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ULTRAVIOLET DISINFECTION OF WASTEWATERS FROM SECONDARY EFFLUENT AND COMBINED SEWER OVERFLOWS

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16. ABSTRACT

A two-year, large-scale pilot investigation was conducted at New York City's Port Richmond Water Pollution Control Plant to demonstrate the application of ultraviolet (UV) disinfection to secondary effluent and to determine the feasibility of applying UV to the disinfection of a wastewater similar to combined sewer overflow (CSO). Three different systems were operated.

The UV process was very effective in the disinfection of secondary effluent. Overall, the study demonstrated that log survival ratios of -3 to -4 could be achieved consistently at practical system loadings. Similarly, it was shown that a log survival ratio of up to -3 could be achieved with primary effluent. The studies also indicated that the submerged quartz systems were more energy efficient than the teflon system in achieving disinfection performance.

A major element of the Port Richmond project was the development of a rationally based protocol for the design of the UV disinfection process. A mathematical expression incorporating the primary process variables was developed and applied to the Port Richmond data base. The model correctly responded to the variables associated with the UV process and was used to develop a number of design curves.

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FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water systems. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. The Clean Water Act, the Safe Drinking Water Act, and the Toxics Substances Control Act are three of the major congressional laws that provide the framework for restoring and maintaining the integrity of our Nation's water, for preserving and enhancing the water we drink, and for protecting the environment from toxic substances. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Water Engineering Research Laboratory is that component of EPA's Research and Development program concerned with preventing, treating, and managing municipal and industrial wastewater discharges; establishing practices to control and remove contaminants from drinking water and to prevent its deterioration during storage and distribution; and assessing the nature and controllability of releases of toxic substances to the air, water, and land from manufacturing processes and subsequent product uses. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community. It is the first report that presents truly substantive data useful for designing ultraviolet light disinfection systems. Through the effort of this research, UV disinfection has come into its own as a viable, cost-competitive alternative to chlorine.

Francis T. Mayo, Director
Water Engineering Research Laboratory

ABSTRACT

A two-year, large-scale pilot investigation was conducted at New York City's Port Richmond Water Pollution Control Plant to demonstrate the application of ultraviolet (UV) disinfection to secondary effluent and to determine the feasibility of applying UV to the disinfection of a wastewater similar to combined sewer overflow (CSO). Three UV systems were operated. Two were submerged quartz systems that differed only in the spacing of the lamps. The third unit used teflon tubes to carry the liquid, with UV lamps surrounding the tubes. All three systems were operated by gravity at flow rates ranging from 400 to 4000 liters per minute. The secondary effluent from the plant was highly variable. Suspended solids ranged between 5 and 50 mg/l, and the UV absorbance coefficient (base e) ranged between 0.25 and 0.5 cm^{-1}. The CSO type wastewater was settled primary effluent characterized by high suspended solids levels and UV absorbance coefficients between 0.5 and 1.0 cm^{-1}.

The UV process was very effective in the disinfection of secondary effluent. The performance of the process could be adequately described on an empirical basis by the initial coliform density, the suspended solids, the UV absorbance coefficient, and the system loading rate, as defined by Q/W, the ratio of the flow to the actual UV output of the system (at 253.7 nm). Overall, the study demonstrated that log survival ratios of -3 to -4 could be achieved consistently at practical system loadings (Q/W). Similarly, it was shown that a log survival ratio as low as -3 could be achieved with primary effluent. The studies also indicated that the submerged quartz systems were more energy efficient than the teflon system in achieving equivalent disinfection performance.

A major element of the Port Richmond project was the development of a rationally based protocol for the design of the UV disinfection process. A mathematical expression incorporating the primary process variables was developed and applied to the Port Richmond data base. The model correctly responded to the variables associated with the UV process and was used to develop a number of design curves. The study demonstrated the importance of the wastewater suspended solids in the application of UV. Coliforms, which are occluded by suspended particles, will not be affected by UV and will, in effect, set the limiting density that can be achieved by UV radiation. The inactivation rate of the coliform was related to the calculated intensity of the UV reactor.

Photoreactivation was determined to have a potentially significant effect on the design sizing of a UV system. In addition, the study evaluated the operating and maintenance requirements of the UV process. Suggestions are made with regard to the system's maintenance and monitoring to enhance the efficiency and cost-effectiveness of the process. A cost analysis of the system shows it to be cost-effective and competitive with chlorination.

This report, prepared by HydroQual, Inc., was submitted by the New York City Department of Environmental Protection in fulfillment of Cooperative Agreement No. CR 807556 under the partial sponsorship of the U.S. Environmental Protection Agency. It covers a period from May 1, 1981, to December 1, 1984.

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SECTION 1

INTRODUCTION

BACKGROUND

A large-scale pilot study was conducted at New York City's Port Richmond Water Pollution Control Plant (WPCP) to investigate the application of ultraviolet (UV) light to the disinfection of secondary effluent and combined sewer overflow (CSO) wastewaters. The studies were directed to assessing the effects of wastewater and operating parameters that influence the UV process, and to developing a rationally based design protocol for UV systems. This report presents the results of the project, which encompassed an experimental period of nearly two years.

The use of UV radiation for the disinfection of wastewaters has gained acceptance as an effective and economically attractive alternative to the use of chlorine or ozone. The number of plants that are installing the process is growing at an increasing rate. As with any newly emerging technology, however, direct field experience is limited and system designs have generally relied on limited empirical information.

The utility of UV as a disinfecting agent has been long understood; with the development of the electric discharge lamp technology, an efficient source of UV also became available. The low-pressure mercury arc lamp was found to emit nearly 90 percent of its light energy at the wavelength of 253.7 nanometers (nm), which is very near the optimum wavelength for germicidal effects. These same lamps are uses for fluorescent lighting (with a phosphor coating); thus the development of mass production techniques for the lighting industry allowed for the efficient and cost-effective manufacture of the mercury arc germicidal lamp. This lamp is almost universally used as the UV source in disinfection systems.

Although the knowledge of UV and the technology for its application has existed for more than 40 years, there had been little incentive to consider its application to treated wastewaters on a large-scale. Chlorination has been long established as an effective and cost-efficient disinfectant, and it has been accepted as the primary disinfection process for wastewater applications. Not until concerns arose over the use of chlorine with regard to aquatic toxicity(1,2) and the creation of chlorinated hydrocarbons in industrial effluents,(3) was a concerted nationwide effort made to develop and encourage the application of alternative disinfection technologies. The U.S. Environmental Protection Agency (USEPA) supported several major research and demonstration projects, and through its Innovative and Alternative Technologies Program, it supported the full-scale application of these new technologies.(4)

In the early 1970s, Roeber and Hoot(5) successfully demonstrated the effectiveness of UV in disinfecting an activated sludge effluent which was being discharged to shellfish waters in St. Michaels, Maryland. This was the first major work demonstrating the use of UV for low-grade waters; the study used an open, shallow tray design with the lamps suspended over the flowing wastewater. The study results demonstrated first-order reductions in coliforms, with tailing effects at the 4-log reduction level. Photoreactivation was also observed in specific controlled tests. The report concluded that UV would be effective in well-controlled, activated sludge treatment plants.

Oliver and Cosgrove(6) and Oliver and Cary(7) investigated a thin film UV design as simulated by suspending UV lamps over a clarifier weir. Their studies demonstrated the effectiveness of UV and considered scale-up applications. They also suggested the inability of UV to affect organisms occluded by particulate matter. Petrasek, et. al.(8) reported on research studies in Dallas, Texas, which investigated the feasibility of UV in disinfecting treated municipal effluents. Two system designs were used;

the first was a shallow tray design similar to the St Michael's study, the second was a system which submerged the quartz encased lamps in the wastewater. The study demonstrated the greater efficiency in the design which submerged the lamps in the liquid. The wastewater parameter which was found to correlate well with disinfection efficiency was the UV absorbance coefficient of the wastewater (at 253.7 nm). The Dallas study also attempted to mathematically estimate the average UV intensity in a complex multi-lamp system. The calculation presumed that the lamp was a line source, and that the energy was emitted radially. Its attenuation would be a function of distance from the lamp and the absorption by the liquid (Beer's Law).

A study funded by the USEPA and conducted at the Northwest Bergen County WPCP in Waldwick, New Jersey(9) successfully demonstrated, on a full-scale, the application of UV to a secondary effluent. This study applied the intensity calculation used in the Dallas report to a dosage expression, assuming ideal flow conditions. The study suggested that the primary water quality parameter is the UV absorbance of the water and showed that UV was economically competitive with chlorination and more cost-effective than ozonation. The study also demonstrated the potential effects of photoreactivation on the design of a UV system. A recommendation which was made in the Northwest Bergen report was to develop the necessary protocols to design and evaluate the UV process. All investigations and design efforts to that point relied on empirical expressions developed from direct piloting.

Johnson and Qualls(10) conducted an investigation into the kinetics of UV disinfection and discussed the importance of hydraulics for effective UV design. A computational model was described for estimating the intensity within a multi-lamp system, based on the assumption that the UV lamp is comprised of a series of point sources which emit energy spherically. The intensity at a given location would be the sum of intensities from each of these point sources. The report also described the effects of particulates, suggesting that the tailing effects normally seen in UV dose-response expressions were due to the inability of UV to affect coliform aggregated or occluded in particulates.

This study effectively evolved from the efforts and results of these last two cited projects. Additionally, New York City was interested in the application of UV to a number of its plants. The City has been concerned about the use of chlorination as a disinfection method, particularly with respect to the costs associated with the use of hypochlorite (the use of gaseous chlorine is not allowed within City limits). There is also the concern expressed by regulatory agencies over the extensive use of chlorine and its impact on the surrounding receiving waters. This becomes particularly evident as disinfection is applied to stormwaters and CSOs prior to discharge.

The concerns which were raised and which generated the need for the Port Richmond study generally related to topics important to the rational design of UV systems:

- Standard procedures for measuring dosage or intensity in complex systems did not exist.
- The impact of variable water quality, particularly that of conventional secondary wastewater treatment plant effluents and of CSO type effluents had not been clearly defined.
- The impact of suspended solids characteristic of secondary effluents or of CSO effluents was not fully understood, particularly with regard to the effect on system design.
- There was a lack of a rational design protocol for the UV disinfection process.

PROJECT OBJECTIVES

The objectives defined for the Port Richmond project can be summarized as follows:

1. Establish and demonstrate a rational design protocol for the design and evaluation of UV disinfection systems which is generically applicable to alternative equipment configurations and wastewater applications.

2. Determine the water quality parameters which are best suited to the sizing and design of UV systems and evaluate their impact on system performance.

3. Demonstrate the performance capability of UV disinfection as it is applied to secondary effluent and to CSO type wastewaters.

4. Establish the impact of photoreactivation on the design of a UV system.

5. Evaluate the operation and maintenance (O&M) requirements for UV systems, and establish the critical system needs to maintain long term effective performance.

6. Estimate the capital and O&M costs associated with the application of UV disinfection and compare these to the costs associated with alternative disinfection processes.

SCOPE OF WORK

Three large scale pilot systems were installed at the Port Richmond WPCP on Staten Island, New York. Each system was capable of receiving flows up to approximately 4000 m^3/day. The units were typically evaluated with effluent from the step aeration activated sludge plant; at times primary effluent was directed to the units. Two of the units were quartz systems which were submerged in the wastewater, with the flow directed perpendicular to the lamps. The two quartz systems differed only in the spacing between the quartz surfaces; the first had a spacing of 5 cm., while the second unit had a spacing of 1.25 cm. The third unit utilized teflon tubes to carry the wastewater, with the UV lamps surrounding the tubes.

The experimental phase of the study was conducted over a period of approximately two years. The units were monitored for disinfection performance over a wide range of loading conditions; water quality was characterized by analysis for UV absorbance at 253.7 nm, suspended solids, turbidity, and chemical oxygen demand. The hydraulic characteristics of the systems were evaluated, as were the capabilities of the systems to effectively deliver UV energy on a long term basis. The output of the lamps was monitored and the transmissibility of the quartz and teflon enclosure was tested. Additionally, the program evaluated photoreactivation, O&M requirements, and the effects of variable water quality.

The analysis of the Port Richmond effort was directed to the development of a mathematical model which properly describes the UV disinfection process and correctly responds to equipment and wastewater variables associated with the process. The model incorporates an estimate of the average intensity in a system based on the point source summation computational technique. The field data collected as part of the experimental program were then used to demonstrate the validity and applicability of the modeling approach.

PROJECT ORGANIZATION

The Port Richmond project was funded through a Cooperative Agreement between the USEPA and the New York City Department of Environmental Protection (DEP). HydroQual Inc. was retained by the New York City DEP to conduct the studies and to prepare the final report. HydroQual personnel were responsible for the design of the facilities and the experimental program, the operation of the pilot plants and the collection of all experimental data, and the analysis of data and preparation of the final report.

The New York City DEP was responsible for the administration of the grant and provided assistance in the operation of the pilot plant. New York City personnel provided direct assistance in the construction of the facility and in the analysis of the field data. Portions of this report were prepared by New York City personnel in addition to a detailed review of the entire manuscript.

SECTION 2

CONCLUSIONS

The Port Richmond project accomplished its two major goals: demonstration of the applicability of UV to the disinfection of secondary effluent and the feasibility of its application to CSO type wastewaters (settled raw wastewater); and the development of a rationally based process design protocol which correctly accounts for the major process and equipment variables associated with the UV disinfection process.

PROCESS DESIGN PROTOCOL

The mathematical model expression developed as part of this project correctly responds to the major UV process and equipment variables. When properly calibrated, the expression can be used effectively for design purposes and for the optimization of system operations. The expression is written as:

$$L = L_o \exp\left\{\frac{ux}{2E}\left[1 - \left(1 + \frac{4EK}{u^2}\right)^{1/2}\right]\right\} + L_{particulate} \qquad (2\text{-}1)$$

where,

L = the bacterial density after exposure.

L_o = the initial bacterial density, as measured immediately before entry into the UV reactor.

x = the distance traveled by an element of water while under direct exposure to UV light.

u = the velocity of the wastewater through the UV reactor; this is calculated as $x/(Vv/Q)$ where V_v is the effective void volume of the UV reactor and Q is the flow rate.

E = the dispersion coefficient characterizing the forward dispersion of the liquid through the UV reactor.

K = the rate coefficient for bacterial inactivation.

$L_{particulate}$ = the bacterial density associated with the wastewater particulates after UV exposure.

The major process variables which must be effectively accounted for in a successful UV design are the hydraulic characteristics of the system, the rate of inactivation, and the densities which are associated with the particulates in the wastewater.

Hydraulics

The ideal design of a UV system has plug flow, turbulent conditions. This can be achieved by designing for effective approach and exit conditions to yield an even distribution of flow across the entire lamp reactor, and by designing the lamp battery to encourage turbulance over the units anticipated flow range.

The dispersion coefficient is a useful parameter to describe the dispersion in the reactor, assuming turbulent conditions. An E approaching zero cm^2/second will reflect a system with plug flow; a complete mix system is desribed by an E approaching infinity.

Inactivation Rate

The rate of inactivation of the bacteria can be described as a function of the intensity in a given reactor. The expression derived from the Port Richmond data is:

$$K\ (sec^{-1}) = 0.0000145\ I_{avg}^{\ 1.3} \qquad (2\text{-}2)$$

where I_{avg} is the average computed intensity for the system.

The density associated with the particulates effectively forms the baseline densities which can be achieved by the UV process. The UV does not penetrate solids; any bacteria occluded by these particles will not be affected by the radiation. An empirical expression was developed from the Port Richmond data to estimate these densities as a function of the effluent suspended solids:

$$\text{Total Coliforms} \ldots\ldots\ldots\ldots\ldots L_{\text{particulate}} = 0.9\ SS^{2.0} \qquad (2\text{-}3)$$

$$\text{Fecal Coliforms} \ldots\ldots\ldots\ldots\ldots L_{\text{particulate}} = 0.25\ SS^{2.0} \qquad (2\text{-}4)$$

Calibration of the model requires the estimation of the dispersion coefficient, E, and the coefficients to describe the inactivation rate as a function of the calculated intensity, and the densities associated with the suspended solids.

The average intensity of UV radiation in a system can be calculated by the point source summation method and described as a function of the absorbance characteristics of the wastewater. This estimate must then take into account the actual output of the UV source and the transmissibility of the enclosures separating the source from the liquid.

The model, when calibrated to a specific wastewater application, can be utilized to develop design curves for specific equipment configurations and can be used to describe the operations of a system. The critical wastewater parameters required for use in the model are the design flow rates, suspended solids, UV absorption coefficient, and the initial density.

PROCESS PERFORMANCE

An effective parameter in describing the sizing of a system is the ratio of the flow rate to the system's UV output, Q/W. This ratio can be used empirically and as an output parameter for the disinfection model. The wattage must account for the losses associated with the aging of the lamps and the degradation of the enclosure surfaces.

The performance of the systems studied at Port Richmond were found to correlate well with the ratio Q/W. Performance is best defined as the log of the survival ratio, Log L/L_o. Coupling the ratio with the UV absorbance coefficient and with the suspended solids of the wastewater greatly improved the correlations. This supports the premise that the most important wastewater characteristics for the design of UV systems are the UV absorbance coefficient, the suspended solids concentration, and the influent coliform densities.

Log survival ratios greater than -5 can be achieved for secondary effluents; the effect of the solids, however, will be additive. Thus, if the solids contribute densities equivalent to 1 to 2 logs, then the actual performances which can be achieved are between -3 and -4. The results of this study demonstrate that UV disinfection is appropriate for secondary plants.

UV is effective in the disinfection of primary effluent. At initial densities greater than 10^7 colonies/100 ml, log survival ratios of -3 can be achieved. Much of the residual density will be associated with the suspended solids in the effluent. The hydraulic loadings to the system are relatively low, due to the relatively high absorbance coefficients of the wastewater.

The UV absorbance coefficient is a necessary parameter in the design and in the effective operation of UV systems. The most effective measure is one which accounts for the scattering of the energy within the wastewater. This true absorbance can be approximated by measuring the absorbance of a filtered sample at 253.7 nm. Only the COD of the wastewater was found to correlate with the UV absorbance coefficient; the correlation was relatively weak. The absorbance coefficient (base e) was found to range between 0.25 cm^{-1} and 0.35 cm^{-1} for a high quality secondary effluent (nitrified), 0.35 cm^{-1} to 0.5 cm^{-1} for typical secondary treatment performance, and 0.5 cm^{-1} to 1.0 cm^{-1} for primary effluent.

Photoreactivation will cause significant increases in the densities of total and fecal coliforms measured after exposure to UV. A log increase of 1.3 was demonstrated with the Port Richmond study; this was independent of the system loading (Q/W). This would cause a three-fold increase in system sizing if it were to be accounted for in performance requirements.

SYSTEM PERFORMANCE

The quartz systems were found to be more efficient than the teflon system, based on the level of energy required to achieve equivalent levels of performance. No significant performance differences were found between the two quartz units, which differed only in the spacing between the quartz surfaces. There may be an improved performance capability in the closely spaced system at low flow rates and/or high initial densities; the reason suggested for this is the laminar flow condition which was prevalent in the widely spaced unit at low flow. This may have caused stratified flow conditions in the UV reactor, which, when coupled with the non-uniform intensity field, can result in reduced performance.

A very clear understanding of the UV output of the reactor and the transmissibility of the quartz and teflon enclosures is important to the proper design and operation of the system. Monitoring procedures are suggested to measure these parameters at appropriate time intervals. Careful control of the average output and the transmittance can affect the economical O&M of the UV system.

An effective control monitor for the UV system may be a continuous measure of the UV absorbance of the liquid (at 253.7 nm). This parameter can be coupled with the flow rate to control the number of lamps or lamp modules in operation at a given time.

Parameters which are important to monitor for effective and successful operation of the UV system are: flow rate, suspended solids, UV absorbance coefficient, and initial and final coliform density; number of lamps in operation, average output of lamp modules (at 253.7 nm), and average transmissibility of the quartz sleeves or teflon tubes.

EQUIPMENT CONSIDERATIONS

The UV process is relatively simple and lends itself very well to modular operation. Is is very flexible in the ability to vary the system operations.

Accessibility of the unit's major components is a critical element in the design of the equipment. Easy access to the lamps and the quartz/teflon enclosures will encourage effective maintenance and will reduce the operational costs of the system.

Proper mating of the lamp and lamp ballasts is critical. The ballasts should be installed remote from the lamp battery; adequate ventilation of power panel should be provided to protect the ballasts from overheating. The power supply and all system monitors/alarms and controls should be remote and elevated from the UV reactors.

Mechanical wipers provide some benefit in keeping the quartz surfaces clean. The teflon tube surfaces were found to foul and required cleaning. In all cases, provision should be made to allow for chemical cleaning of the UV reactor.

COSTS

The UV disinfection of secondary effluent is economical and is cost competitive with alternative disinfection systems, including chlorination and ozonation. The costs of the process are capital intensive; the O&M costs are dominated by the costs associated with the replacement of the lamps and the power to operate the system.

SECTION 3

RECOMMENDATIONS

The modeling approach developed in this study to design and control the operation of UV disinfection should be applied in future full-scale applications. The data collection protocol, and the application of this data to the calibration of the model, should be followed; design scenarios can then be tested with the calibrated model to optimize the system.

The calibrated model should be applied to the operation of the full-scale system. This would be in conjunction with the maintenance protocols suggested herein, and the proper monitoring of system output and the transmissibility of the enclosures.

The utility of the calculation method should be further evaluated in estimating the average intensity of UV radiation within the reactor. This is in particular regard to relating the inactivation rate to the calculated intensity.

Data should continue to be generated and compiled regarding the site specific sensitivity of bacteria (e.g., total and fecal coliforms) to UV radiation and the effect of suspended solids on performance efficiency. These are empirical inputs to the disinfection model; as data are generated at different plants, greater confidence will be gained in estimating the appropriate coefficients.

Evaluations should be conducted to assess the benefit of varying the lamp voltage as an energy concentration measure. The effect on lamp life and actual output should be determined.

Studies should be conducted to determine the effect of UV on other indicator organisms (fecal streptococcus, enterococcus, as examples), on the major pathogenic bacteria, and on viruses. The effects can be studied relative to the effects of UV on the primary coliform indicators.

SECTION 4

DESCRIPTION OF FACILITIES

PORT RICHMOND WATER POLLUTION CONTROL PLANT

The Port Richmond WPCP is located on the northern shore of Staten Island in New York City. Port Richmond is 1 of 12 wastewater treatment plants owned and operated by the New York City DEP. This WPCP was first built as a primary facility in 1953. In the early 1970s it was upgraded to a step aeration activated sludge facility. Design capacity is 227 million liters per day (mld) or 60 million gallons per day (mgd) for the secondary system. The combined collection system covers a 62 square kilometers (24 square miles) drainage area, and receives residential and industrial wastewater (approximate volume ratio of two to one). Construction of separate storm sewers is planned for the area.

A layout of the plant is presented on Figure 4-1. Port Richmond has three inlet channels with bar screens for coarse solids removal. The flow then passes through four primary settling tanks with 1.2 hours detention time. Five cyclone degritters separate grit from the primary sludge. Four step aeration tanks with four passes each provide five hours treatment, followed by six final settling tanks with four hours detention time. Flow in excess of the secondary design flow is bypassed directly from the primary tanks to the final effluent channel.

Seasonal chlorination is practiced at Port Richmond. Liquid sodium hypochlorite is added to the effluent from May 15 through September 30. Two chlorine contact tanks provide 45 minutes detention at average flow. The final effluent is discharged through a 2.4 meter diameter outfall into the Kill van Kull, approximately 300 meters from shore. The wastewater

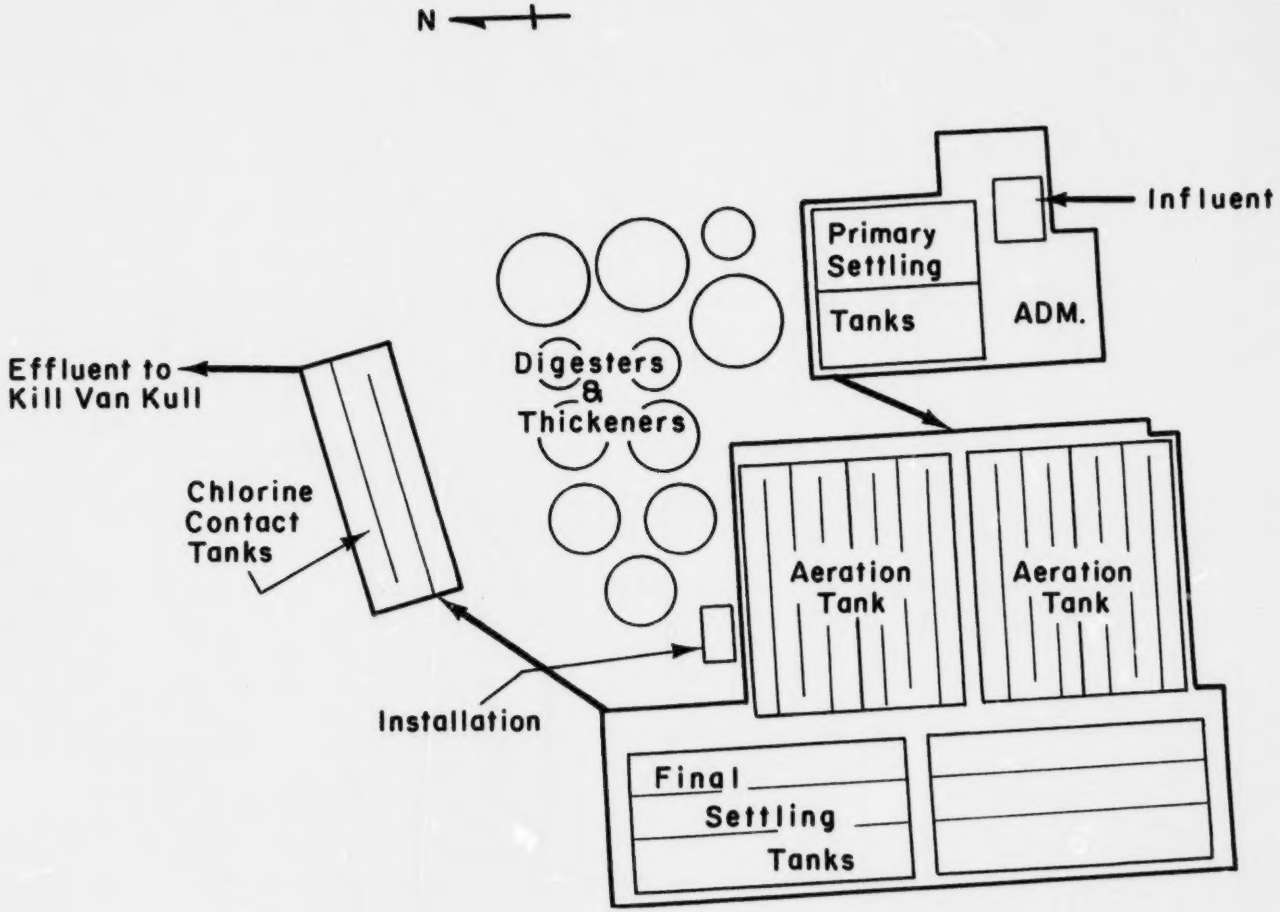

N
Influent
Primary Settling Tanks
ADM.
Digesters & Thickeners
Effluent to Kill Van Kull
Chlorine Contact Tanks
Aeration Tank
Aeration Tank
Installation
Final Settling Tanks

Figure 4-1. Layout of Port Richmond WPCP.

sludge is further processed in six thickeners and three digesters, then pumped into vessels at dockside for subsequent offshore disposal.

Plant Performance

The field effort for the UV demonstration project took place from November 1981 to October 1983. During this time, Port Richmond plant flows averaged 155 mld (41 mgd) and the influent averaged 140 mg/l SS and 148 mg/l BOD_5. Effluent concentrations averaged 17 and 14 mg/l for suspended solids and BOD respectively. Plant flows during storm events reached up to 378 mld (100 mgd). A summary of the plant data for suspended solids, BOD, pH, and temperature can be found in Table 4-1. Additional data on the chlorination process is given in Table 4-2. Chlorine consumed for the summer seasons of 1982 and 1983 were 298,000 and 362,000 liters, respectively, maintaining an average residual of 0.5 mg/l. Port Richmond remained in compliance with all applicable effluent limitations contained in its discharge permit during this time. There were no major plant upsets other than short term difficulties encountered as a result of varying industrial influents, primarily of a detergent nature, and on one occasion, an oil spill.

PILOT PLANT DESCRIPTION

General Layout

The UV test facility was located north of the building containing the secondary aeration tanks. A layout of the UV pilot plant is shown on Figure 4-2. This location was appropriate for access to the plant effluent and a discharge channel as well as space to construct a shelter for the UV units. The existing spray water system at Port Richmond uses the plant secondary effluent for suppression of foam on the aeration tanks. The standby spray water pump (22 kW) located in the sludge gallery was disconnected from the discharge header and connected to a new 25 cm diameter steel pipe built to convey the plant effluent out of the building and approximately 60 m to a head tank. This constant head, steel tank, 1.2

TABLE 4-1. PORT RICHMOND WPCP INFLUENT/EFFLUENT MONTHLY AVERAGES[a]

Month	Flow (mld)	Influent SS (mg/1)	Influent BOD_5 (mg/l)	Effluent SS (mg/1)	Effluent BOD_5 (mg/l)	Effluent Temp (°C)	pH Max.	pH Min.
Nov. 81	137	162	162	18	10	16	7.1	6.1
Dec.	147	140	179	22	18	12	8.2	5.9
Jan. 82	154	129	164	18	12	9	6.9	5.9
Feb.	171	149	164	27	23	9	6.8	6.1
Mar.	157	147	188	26	19	10	6.8	6.1
Apr.	166	129	161	26	18	11	7.7	6.0
May	140	173	153	30	19	14	7.0	6.2
June	157	144	134	15	11	17	7.2	6.0
July	146	131	127	16	13	20	7.4	6.0
Aug.	142	166	144	14	11	21	6.9	6.1
Sep.	151	239	208	16	13	20	6.9	6.1
Oct.	137	137	170	16	17	19	7.1	6.0
Nov.	138	131	155	12	15	16	7.2	6.0
Dec.	138	153	166	15	11	-	7.1	6.2
Jan. 83	154	142	140	18	17	11	6.9	6.1
Feb.	160	148	155	18	15	9	6.9	6.1
Mar.	203	108	98	17	14	9	6.8	6.2
Apr.	212	88	96	10	9	10	7.0	6.2
May	168	106	123	10	10	13	6.9	6.1
June	169	115	115	11	10	-	6.9	6.2
July	146	145	149	13	20	19	6.9	6.2
Aug.	141	101	109	9	13	20	7.0	6.1
Sep.	139	129	147	8	8	20	6.9	5.4
Avg.	156	140	148	17	14			

[a] New York City Department of Environmental Protection analyses

TABLE 4-2. CHLORINATION AT PORT RICHMOND WPCP

Month	Flow (mgd)	Flow (mld)	Chlorine Used (gallons)	Chlorine Used (liters)	Chlorine[a] Residual (mg/1)	Effluent Fecal Coliforms/100 ml Geometric Mean
May 1982[b]	38.5	146	7,820	29,600	0.7	16
June	41.5	157	16,470	62,340	-	-
July	38.6	146	18,850	71,350	0.6	35
August	37.5	142	16,170	61,200	0.5	34
September	39.9	151	19,340	73,200	0.4	82
May 1983[b]	45.9	174	11,250	42,580	0.6	77
June	44.6	169	21,400	81,000	0.4	24
July	38.5	146	26,110	98,830	-	44
August	37.3	141	20,500	77,590	-	105
September	36.8	139	16,300	61,700	-	45
Total			659,380	174,210		
Average		151 mld	66,000 l/month		0.5	44

[a] Chlorine residual was measured at influent to contact tanks
[b] Month of May from 15th to the end of the month

m wide x 1.2 m long x 2.4 m high was located adjacent to the plant building wall and just outside the temporary building. The temporary building was 8.5 m x 7.6 m, housing three UV units. The effluent flowed from the head tank, by gravity, through the UV units and was discharged to the secondary plant bypass channel, joining regular plant effluent prior to the plant outfall. A 30 cm diameter PVC pipe provided the overflow from the head tank directly to the bypass channel. The difference in head from the head tank overflow pipe to the UV unit influent pipe was approximately 2.1 m. The head tank volume was approximately 3000 liters.

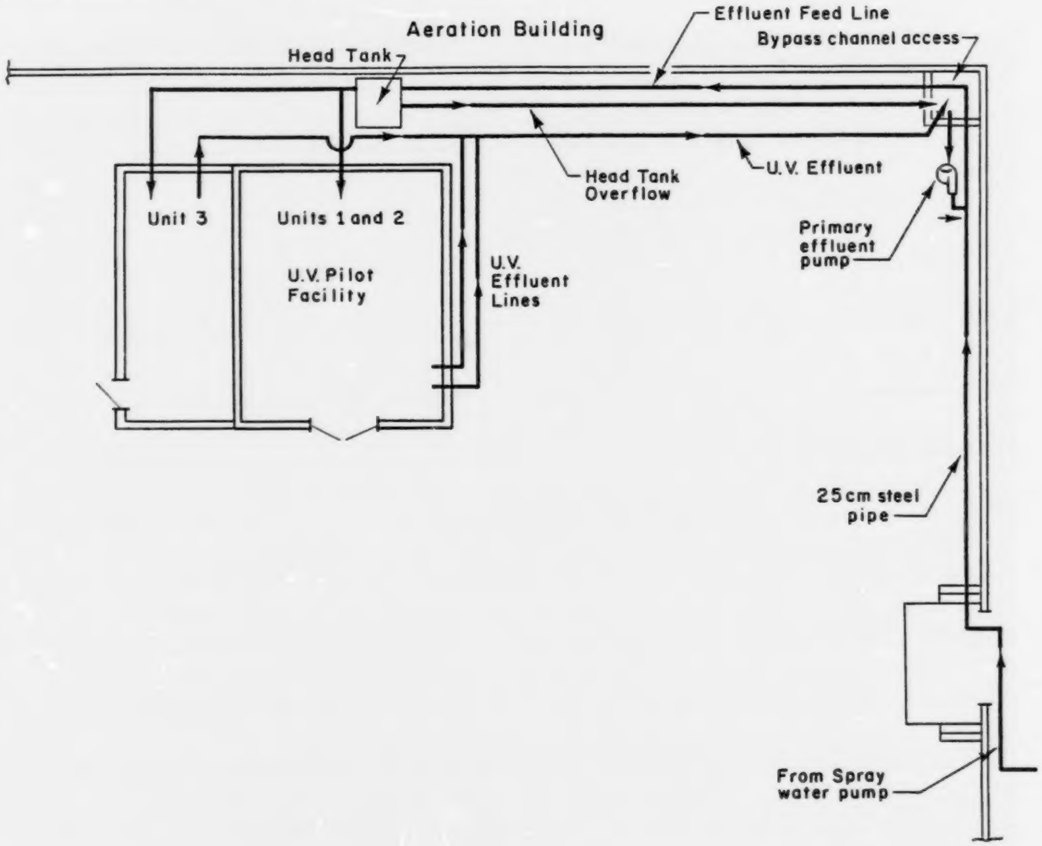

Effluent Feed Line
Aeration Building
Head Tank
Bypass channel access
Head Tank Overflow
U.V. Effluent
Unit 3
Units 1 and 2
U.V. Pilot Facility
U.V. Effluent Lines
Primary effluent pump
25cm steel pipe
From Spray water pump

Figure 4-2. Schematic of UV pilot plant layout at Port Richmond WPCP.

An additional connection was made to the pipe leading from the spray water pump to the head tank. A second pipe, 20 cm diameter steel, connected to a 5000 lpm/pump, was installed in an access shaft in the primary bypass channel. Primary effluent, used to simulate the quality of settled CSO wastewater, was pumped from this bypass channel to the head tank.

Other PVC piping and valves were used, as necessary, to connect the head tank, the UV units, and provide influent and effluent channels for the necessary flow routing. Figure 4-3 presents a schematic layout of the pilot facility.

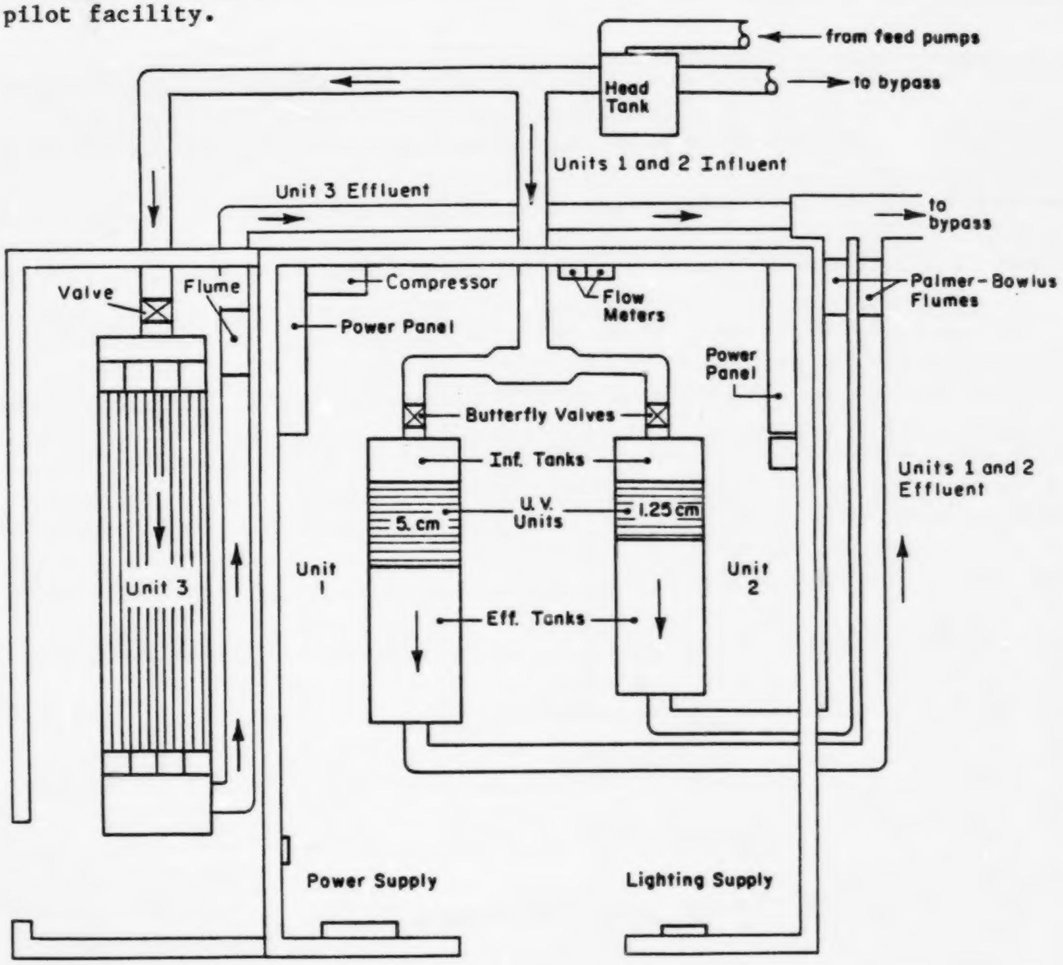

from feed pumps
to bypass
Head Tank
Units 1 and 2 Influent
Unit 3 Effluent
to bypass
Valve
Flume
Compressor
Flow Meters
Palmer-Bowlus Flumes
Power Panel
Power Panel
Butterfly Valves
Inf. Tanks
U.V. Units
5. cm
1.25 cm
Units 1 and 2 Effluent
Unit 3
Unit 1
Unit 2
Eff. Tanks
Power Supply
Lighting Supply

Figure 4-3. Layout of pilot facility.

Units 1 and 2 were housed in the main section of the building (6.1 m x 7.6 m). The third unit was delivered at a later date, at which time an addition was constructed to house the unit.

Flow Control and Measurement

Flow to the UV units was controlled by manual adjustment to 25 cm PVC butterfly valves on the influent line coming from the head tank. Flow was monitored in the effluent channels after passage through the UV units. Palmer-Bowlus flumes (25.4 cm) were installed in the effluent channel of each unit. Depth at the jump was monitored by two ISCO Model 1700 bubble type flow meters. Manual depth readings were also taken at the flumes on a routine basis. The initial design called for each UV unit and associated piping to have a capacity of 3.8 mld (1 mgd). Actual flow through a single UV unit ranged from 0.5 to 4.0 mld during the experimental program.

Flow routing was such that Units 1 and 2 could be operated separately or together. When Unit 3 was added, it could be operated separately or together with either Unit 1 or 2. Only two out of three units could receive flow at the same time. Operating options were the same for secondary effluent testing and storm event testing; for the latter the bypass channel pump was in operation in lieu of the spray water pump.

Unit Influent/Effluent Tanks

The pilot plant was built above ground and separate from the existing treatment plant. Units 1 and 2 were provided with an inlet tank of epoxy coated mild steel for each unit, 0.46 m long, 1.17 m wide, and 1.22 m high and an effluent tank of the same material 1.83 m long, 1.19 m wide and 1.22 m high. A steel weir plate with angle brace was provided in the effluent tanks to maintain submergence of the UV lamps. An additional plywood baffle was inserted in the influent tank to create a stilling wall.

Unit 3 contained an influent splitter box divided into four sections and a perforated flow distribution baffle which contained 3.17 cm orifices;

these were lined up with the center line of each teflon tube receiving wastewater flow. All three units had flanged inlets and outlets for connection to the PVC influent and effluent pipes.

Construction Chronology

Construction of the pilot plant started in May 1981. By June, the steel piping and head tank were in place. The wood frame building sheltering Units 1 and 2 was completed in July. The electrical feed lines to the building and associated power panels, switches and motor starters were installed in August. By the end of October 1981 Units 1 and 2 were delivered, installed and connected. The third UV unit was delivered and installed during the summer of 1982.

Power Supply

Electrical power to the pilot plant was taken off an existing 480 volt, three phase, three wire motor control center located in the sludge pumping station, just above the area containing the spray water pumps. Electrical installation included approximately 80 meter by 5 cm conduit to a new 480 volt AC, 60 Hz load center mounted inside the pilot building. The load center consisted of a 100 ampere main and 6 branch circuits, one 15 amp and five 30 amp, 3 pole breakers.

This work was performed by New York City DEP electricians to provide appropriate power to the pilot plant, and was installed in accordance with New York City and National Electric Codes. All other electrical equipment associated with a particular UV system was the responsibility of the manufacturer. A kilowatt-hour (kW-hr) meter for monitoring the power usage by UV Units 1 and 2 was supplied and installed by the manufacturer.

UNIT DESCRIPTION

Units 1 and 2

Two UV disinfection systems were located in the original confines of the pilot plant building. These units were fabricated by the same manufacturer. Each unit contained 100 lamps in a symmetrical (10 x 10) array, perpendicular to flow. The lamps were Voltarc 40 watt (nominal) G36T6 VH, 0.9 m long, with an effective arc length of 0.75 m. The rated output at 253.7 nm for each lamp is approximately 14 W. Each was enclosed in a 23 mm diameter quartz sleeve. The only difference between the two units was that the spacing between the quartz surfaces was 5.0 cm in Unit 1 and 1.25 cm in Unit 2. The lamp battery dimensions (internal) were 0.74 m long by 0.69 m high and 0.73 m wide for the widely spaced unit (Unit 1) and 0.40 m long by 0.35 m high by 0.73 m wide for the narrowly spaced unit (Unit 2). The lamps were cleaned by a mechanical wiper system. The wiper blade was cable driven at a variable stroke rate by a pneumatic cylinder; teflon wiper rings sealed about each quartz sleeve would wipe the surface as the wiper plate moved from one end to another of the lamp battery.

Each UV system had a separate power panel containing a shutoff switch for each of three banks of lamps (30, 40, 30) and light emitting diode (LED) pilot light indicators for each lamp. The panel contained Universal Thermalmatic ballasts, each rated for two G64T5 germicidal lamps, operating at 480 V, 60 Hz, lamp current of 430 mA, output voltage 700 V, and sound rating B. Other monitoring equipment in the panel consisted of UV intensity monitors for each bank of lamps, a lamp temperature probe, elapsed time of operation totalizers, and a wiper timing device.

Other equipment supplied by the manufacturer in conjunction with Units 1 and 2 were an air compressor for driving the wiper mechanisms, a variac control for modifying lamp voltage, and a kW-hr power meter. The equipment could be accessed and maintained on-site. The sides of the lamp units were provided with plexiglas shields to protect the operator from exposure to UV at the lamp end.

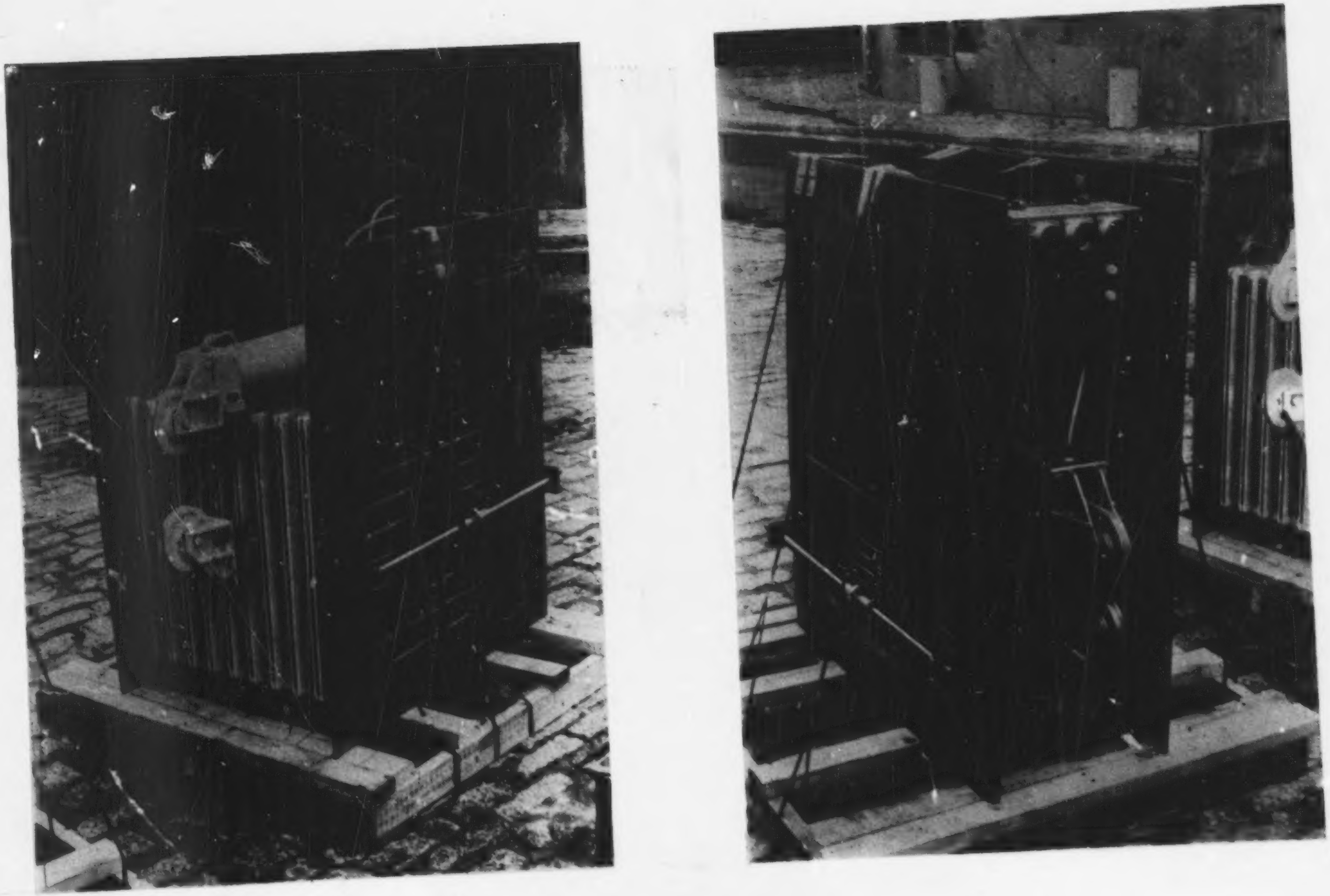
The third unit was a system which utilized teflon tubes to carry the wastewater. This system was delivered to the site in the summer of 1982. An addition was constructed to the original building to house the unit. Unit 3 was connected to the same influent and effluent lines as Units 1 and 2. The wastewater flowed through teflon tubes; the UV bulbs were parallel to the flow and not immersed in the wastewater.

Unit 3 contained 32 teflon tubes, 6.0 cm in diameter and 3 meters long. They were arranged 8 across and 4 high. The tubes were on 15 cm centers. There were 72 UV G64T5 lamps, 1.5 m long, symmetrically arranged at 15 cm centerline spacings. The unit could be operated with up to four independent compartments, each with eight teflon tubes. As will be discussed in later sections, only one compartment was typically used for the study. Additionally, in 1983, the tubes in the active compartment were replaced with new tubes which had a diameter of 8.9 cm.

The steel cabinet assembly housing the teflon tubes, UV bulbs, inlet and outlet tanks measured 4.9 m long by 1.8 m wide by 0.9 m high. This assembly was not weathertight. The cover was in movable sections, which could be opened by sliding on rails. The UV bulbs were on racks which could be lifted for access. The ballasts were housed in compartments attached to the top of each lamp rack. The cabinet assembly also contained four UV intensity monitors, a 115V, 60 Hz fan, lamp temperature indicator, and 220 V, 60 Hz power connector.

Photographs

Figure 4-4 presents photos of the two quartz units before installation with the influent and effluent tanks. Note the quartz tubes, the cable drive for the mechanical wipers and the wiper plate. Recall that the flow would be in a direction perpendicular to the quartz. A photo of the widely spaced unit is shown on the left side panel of Figure 4-5 as installed; the effluent tank is in the foreground. The lower panel of Figure 4-5 shows one of the two power panels installed for the quartz units. The panel

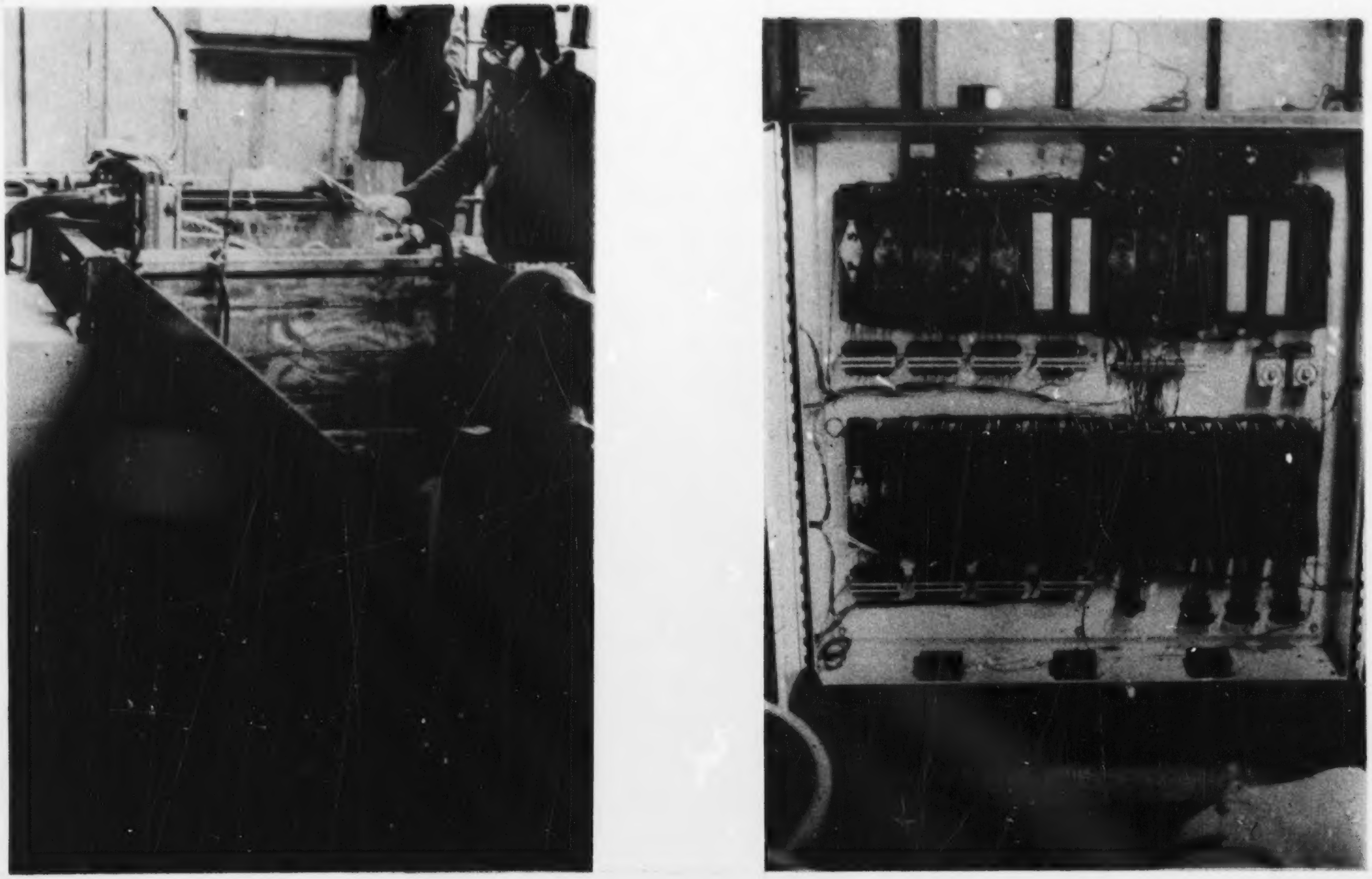


Unit 2

Unit 1

Reproduced from
best available copy.

Figure 4-4. Units 1 and 2, without influent and effluent tanks.



Unit 2

Power Panel, Unit 1

Figure 4-5. Unit 2, with tanks; power panel for Unit 1.

houses the ballasts, LED displays, wiper controls, elapsed time clocks and UV intensity meter. Note the high volume ventilation fans at the bottom of the panel.

Photos of the teflon unit (Unit 3) installed at the facility were of poor quality. To give the reader a perspective of the unit, however, two photos of a very similar unit are presented on Figure 4-6. The upper panel shows the unit casement, the bottom panel gives a view looking down into the unit. This photo shows four teflon tubes across; the unit at Port Richmond had eight.

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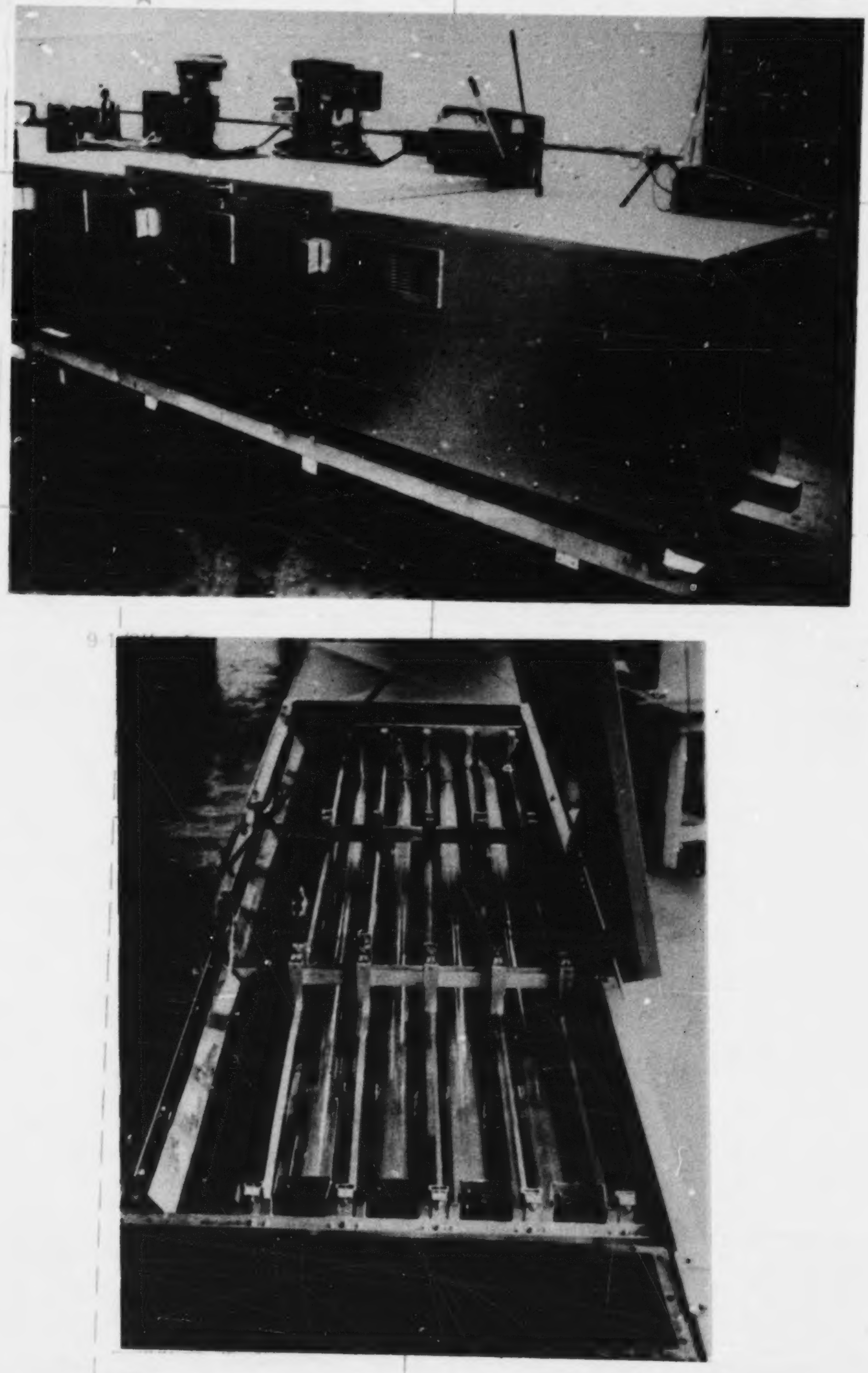

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Figure 4-6. Photographs of unit similar to Unit 3.

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SECTION 5

EXPERIMENTAL PROGRAM AND PROCEDURES

This section discusses the experimental program and procedures used in the Port Richmond study. A summary of the experimental program is presented, sampling procedures are discussed, and routine analytical and metering techniques are described. Special studies which were conducted as part of the program are also presented.

EXPERIMENTAL PROGRAM - GENERAL OVERVIEW

A major objective of the project was to establish and demonstrate a rationally based protocol for the design of UV disinfection systems. The work at Port Richmond was aimed at collecting field performance data to demonstrate the validity and application of such a design procedure, or, if necessary, to modify the method. Other objectives of the field program were to investigate the effect of wastewater variability on UV performance, to assess the efficiency of UV disinfection on CSO type wastewaters, and to determine the effect of photoreactivation.

The preparation for and the installation of the two quartz units (Unit 1 and 2) fabricated by Pure Water Systems was accomplished between March 1981 and November 1981. The field test program for these two units began in early December 1981 and continued until early September 1983. The installation of the teflon unit (Unit 3) fabricated by Enerco, Inc. was accomplished May through August 1982. Sampling was initiated for this unit in late August 1982 and continued intermittently through August 1983.

A general summary of the sampling program and operating conditions for the three units during the entire field study is presented in Table 5-1.

TABLE 5-1. GENERAL SUMMARY OF SAMPLING PROGRAM AND OPERATING CONDITIONS AT PORT RICHMOND

Time Period	Sampling and Operating Conditions[a]
12/1/81 to 5/20/82	Routine sampling of Units 1 and 2 only. All three banks of lamps were on. From 12/1/81 to 3/10/82 the variac was set at 90%. Subsequently it was set at 100%.
5/25/82 to 7/7/82	A sampling series on Units 1 and 2 only. Conditions were always with 3 banks of lamps on. Three flows per day were evaluated. The sequence of flows and samplings were randomized from day to day; the units were acid/detergent cleaned each day they were sampled.
7/13/82 to 8/11/82	A sampling series on Units 1 and 2 only. Conditions in this series were 2 banks of lamps on; three flows per day. The sequence of flows and samplings were randomized from day to day. The units were acid/detergent cleaned each day they were sampled.
8/17/82 to 10/3/82	Units 1 and 2 were shutdown for rewiring and other repairs. Some routine sampling of the newly installed teflon unit (Unit 3) was conducted through the first two weeks of September. System problems forced shutdown, however.
10/4/82 to 11/14/82	Routine sampling of Units 1 and 2. Three banks of lamps were on for October; two banks of lamps were on for November. The teflon unit was down during this period.
11/15/82 to 1/26/83	Several wiper studies were attempted on Units 1 and 2. Three banks of lamps were on and the flow was constant through each study. Various methods were evaluated to clean teflon tubes in Unit 3. Subsequent inspection of all 3 units indicated extreme fouling. Performance data were not considered of any use for this period.
1/27/83 to 4/10/83	Limited sampling was conducted on Units 1 and 2 with 3 banks of lamps on until 3/17/83; the units were then switched to 2 banks. Unit 3 was sampled in March with flow through only one channel in most cases.
4/11/83 to 5/11/83	A sampling series was conducted for Units 1 and 2, with 2 banks of lamps on and 3 flows per day. The sequence of flows and samplings were randomized from day to day. The units were acid/detergent cleaned daily. Unit 3 was also sampled during this period with flow through only one compartment.
5/12/83 to 6/26/83	Direct sampling of the units was discontinued. Laboratory batch experiments were conducted. Both Units 1 and 2 were relamped.
6/27/83 to 8/25/83	Routine sampling of Units 1 and 2 was conducted with 2 banks of lamps on. The teflon unit (Unit 3) was sampled with flow through one channel; the unit was shutdown on 8/25/83. Units 1 and 2 were acid/detergent cleaned daily. A series of photoreactivation tests were performed during this period.
8/30/83 to 9/8/83	Primary effluent was used as the influent to Units 1 and 2. Sampling was conducted with 2 banks on, at three flow rates per day. The units were acid/detergent cleaned each day of sampling.

[a] Unit 1: widely spaced quartz unit (5 cm spacing).
Unit 2: closely spaced quartz unit (1.25 cm spacing).
Unit 3: teflon system.

SYSTEM MONITORING AND MAINTENANCE

The operating conditions of the UV systems were recorded each work day. The power meter and intensity meter readings, wiper cycle rate, lamp temperature and lamp inventory were recorded once each day. Flow rates were recorded at each sampling. Units 1 and 2 were also routinely cleaned on each sampling day.

Power

A power meter measuring the kW-hrs consumed by the two quartz units (Unit 1 and 2) was read once per sampling day. A Variac was used to regulate the applied voltage to the two units. The voltage was always set at 100 percent (480 V) except at the start of the experimental program (December 1, 1981 to March 10, 1982) when it was set at 90 percent. The power consumed by Unit 3 was not continuously monitored.

Lamp Inventory

The number of lamps in operation and the specific lamps that were out were recorded for each unit on each sampling day. The LED indicators were provided for each lamp in the control cabinets of Units 1 and 2; however, it was found that they were not a good indicator of lamp operation. The LEDs themselves would often fail. It was generally necessary to confirm the indicator by visually inspecting the lamps. With time it became more efficient to simply inspect the lamps directly.

Lamp indicators utilizing fiber optics were provided for each pair of lamps (connected to one ballast) in Unit 3. The indicators were mounted on the outside of the unit and functioned well throughout the study. However, only one of each pair of lamps had a fiber sensor; although it would provide an indication of one lamp, it was necessary to assume the same status for the second lamp of the pair. Actual visual inspection was very difficult in this particular unit design.

Lamp Temperature

Attempts were made to measure lamp skin temperature directly. A single probe was provided for Units 1 and 2. Normally it was mounted on a single lamp in Unit 1. The probe was a thin thermister rod which was attached to the lamp skin by wrapping it with a strip of aluminum foil. The readings which were obtained were not considered wholly accurate, nor representative of true lamp skin temperature conditions throughout the unit nor along the length of the lamp. The temperature meter was inoperable during several periods of the study; beyond March 1983 the sensor was found to have completely deteriorated and temperature measurements were discontinued for the remainder of the program.

A lamp temperature sensor had also been supplied with the teflon unit. It was found to be unreliable and was not used.

System Cleaning

The quartz units were chemically cleaned each sampling day from May through August 1982, and from March 1983 to the end of the experimental program. Flow would be shut off and approximately 250 ml of concentrated sulfuric acid (objective was to adjust pH to between three and four) and a small amount (one to two capfuls) of concentrated grease cutting detergent or cleaner was added to the influent tank. The wiper stroke frequency was adjusted to once every 10 minutes during the cleaning period. After approximately one hour, the flow was turned back on and the units were flushed at a high flow rate for approximately one-half hour. The wiper rate was then readjusted and the flow rate set for the first sampling.

A routine cleaning procedure for the teflon unit was not established, although the system was found to foul. Simple adjustment of pH and recirculation of a cleaning solution was not effective; the teflon required physical wiping or scrubbing to be cleaned effectively.

Wiper Operation

The wiper rate for each of the quartz units was recorded daily. The wiper was in operation for most of the study period; the only exception being the period (December 1982 to January 1983) when an attempt was made to directly evaluate the efficiency of the wiper. The wiper rate for the first six months of the project was six cycles per hour for each unit. The rate was subsequently changed to one cycle per hour. A cycle is defined as one pass across the lamp battery.

Intensity Measurements

Intensity readings were routinely taken for Units 1 and 2 once each sampling day. If the units were chemically cleaned that particular day, the intensities would normally be measured both before and after cleaning.

Intensity measurements at 253.7 nm were made using an International Light IL 570 Radiometer which used an SEA-240 detector with a W-Quartz wide-eye diffuser and a narrow band NBS 254 filter. Intensities were measured at three fixed points across the exit plane of the lamp battery, spaced 25.4 cm apart. The detector, which was mounted on a long rod, would be set on the wiper slide bar for each reading to maintain a consistent vertical position in the exit plane. The intensity at the halfway point across the influent plane of the lamp battery was also checked (again with the detector resting on the wiper bar) during certain periods of the study. The intensity on the influent side was the only reading taken from July to September 1983, since the exit bank of lamps in each unit were not operated during this period.

The detector was positioned 3.5 cm away from the plane of the exit bank of lamps in Unit 1, and 5.1 cm in Unit 2. The detector was recalibrated in January 1983. After calibration, the detector was remounted; as a result, the position from the lamps was altered such that the detector was 0.64 cm closer to the plane of the bulbs in both units.

Intensity Monitors

Each quartz unit was equipped with an internal intensity monitor for each lamp bank. The sensors were mounted at the top of each unit, directly above the top lamp row. Blades were attached to the wiper to clean the sensor window. Calibration of the monitors involved setting each readout to 100 percent with all lamps on; each sensor could then be read individually. At the start of the program, intensity readings were recorded daily. The measurements were found to be inconsistent and not representative of actual conditions. In March 1982, the meter in Unit 2 failed and in June 1982 the Unit 1 meter failed. Since the intensity monitors were not considered effective, they were not repaired and not used for the remainder of the study.

The teflon unit was equipped with four internal intensity monitors. The sensors, in this case, were inserted into the teflon tube and were designed to sense input from all directions; the sensor was mounted behind a teflon sphere which acted as a light collector. Considerable problems were encountered, primarily with regard to component failures. The original monitors were replaced shortly after installation. The second series of monitors was found to give inconsistent readings and eventually failed.

Flow Rate

The flow rate through each of the three units was measured by 25.4 cm Palmer-Bowlus flumes in each effluent channel. Depth at the jump was monitored by an ISCO Model 1700 bubbler type flow meter. Manual depth readings at the flumes were also typically taken.

Flow Rate Calibrations—

Each Palmer Bowlus flume was calibrated using a lithium chloride brine (Foote Mineral Company) as a tracer. A solution of known lithium concentration was continuously metered at a known flow rate into the influent tanks of each quartz unit and into the effluent tank of the teflon unit. A mixer was placed in the effluent tanks to assure complete mixing of the lithium with the wastewaters. Samples were taken from the effluent flume of each unit at least four times per run after steady state had been achieved. The volume of lithium pumped and the duration of pumping was recorded for each run in addition to the wastewater height in the flume. Background and stock samples were taken several times during each series of runs. Lithium was analyzed by flame AAS techniques using an Instrumentation Laboratory AA/AE Spectrophotometer No. 751. Tests were conducted through the full capacity range of the flumes.

The resulting calibration curves are presented on Figure 5-1. These were used to convert the routinely measured flume depths to the actual flow rate through each unit.

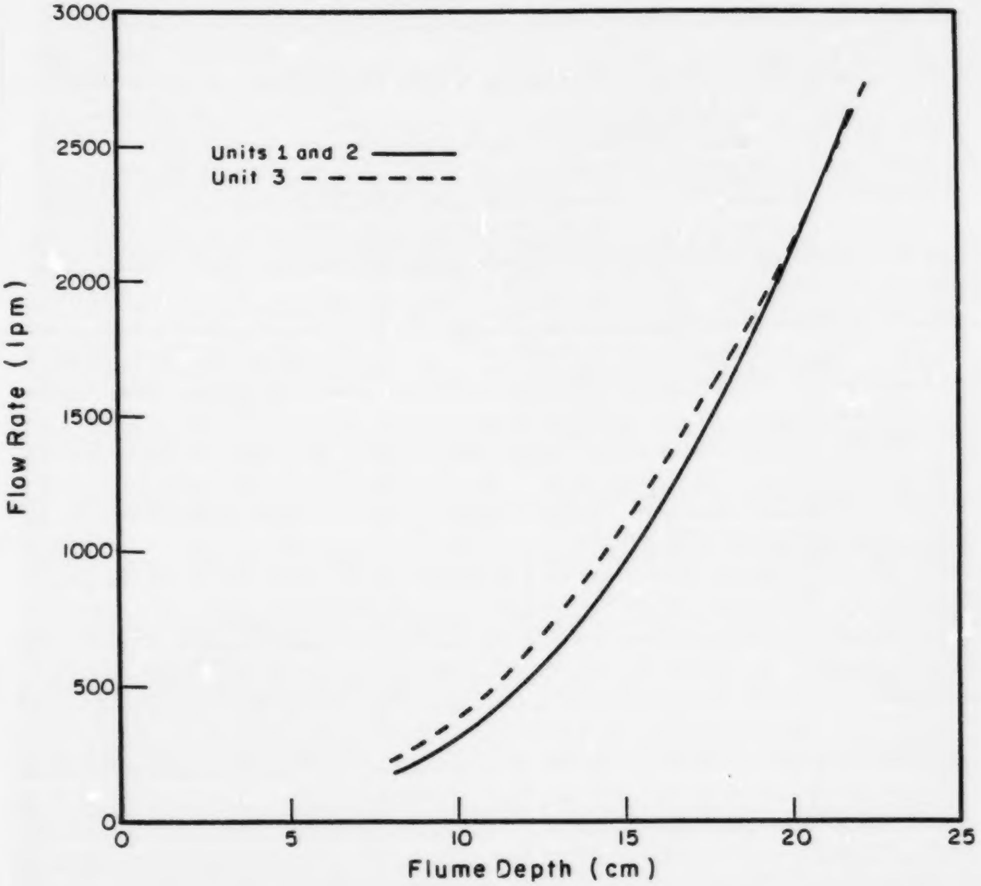

Figure 5-1. Calibration of Palmer-Bowlus flumes for measurement of flow rate through each unit.

SAMPLING AND SAMPLE HANDLING

All sampling was done on a grab basis. Samples were taken in one liter glass bottles which had been washed and sterilized by heating in a 180°C oven for several hours. Influent samples were taken from the influent tanks of each unit. At each sampling only one influent sample was taken regardless of whether one or three of the units were sampled. Effluent samples from Units 1 and 2 were taken from the effluent tanks using a Wheaton Remote Sampler. The closed sample bottles were submerged in the effluent tank and positioned at the mid-point of the lamp battery, approximately 15 cm from the last vertical row of lamps. The bottle was then opened to draw the sample. Effluent samples from the teflon unit were taken from the effluent flume when all channels were in operation. When only one channel was in use, samples were taken at the channel overflow weir. All bottles used for effluent samples were painted black as protection against light penetration. Less than five minutes was normally required to complete a sampling (influent and effluent samples).

Sampling sequences were usually randomized from day to day to minimize any effect diurnal variations in water quality may have had. Three flow conditions were typically run daily in a randomized order. In addition, the order of sampling the effluent points was varied from sampling to sampling.

All bacterial analyses were accomplished at the Port Richmond laboratory within two hours of sampling. Suspended solids analysis was also performed on-site on the same day sampled.

All filtrations required for analysis of soluble components were done at Port Richmond the day the sample was taken. These samples, along with the unfiltered samples, were kept refrigerated and shipped to HydroQual's associated laboratory, General Testing Corporation in Hackensack, New Jersey. Aliquots taken for nitrogen analyses were additionally preserved by acidification to a pH less than two.

Pretreatment of Primary Effluent Samples

Bacteria protected within large clumps of solids present a problem in coliform density determinations in a CSO type wastewater. Prior to the start of the experimental program, the effect of blending on the measured coliform density of a primary effluent sample was evaluated in the laboratory. Primary influent samples from a local treatment plant were settled in the laboratory for approximately 15 minutes. In Run 1 (August 18, 1981) a 700 ml sample of the supernatant was transferred to a blender and samples were withdrawn for total and fecal coliform enumeration (USEPA membrane filter procedure) after 0, 3, 6, 10, 20, and 40 seconds of blending time at high speed. A second 700 ml sample was exposed to UV light for five minutes with constant mixing. The sample was transferred to the blender (which was wrapped in aluminum foil as protection against light penetration) and samples withdrawn after 0, 3, 6, 10, 20 and 40 seconds of blending. The results are presented in Table 5-2 and on Figure 5-2.

TABLE 5-2 EVALUATION OF BLENDING FOR PRETREATMENT OF PRIMARY EFFLUENT SAMPLES

	Run 1[a]				Run 2		Run 3
Blending Time	(August 18, 1981) Unexposed Sample		Exposed Sample[b] (5 minutes)		(August 24, 1981) Exposed Sample (8 minutes)		(August 26, 1981) Exposed Sample (8 minutes)
(seconds)	Total Coliform	Fecal Coliform	Total Coliform	Fecal Coliform	Total Coliform	Fecal Coliform	Fecal Coliform
0	4.4×10^7	2.4×10^7	1.2×10^5	2.8×10^4	1.3×10^4	5.2×10^3	9.3×10^5
3	6.7×10^7	2.7×10^7	TNTC[c]	TNTC	5.8×10^4	4.2×10^4	1.9×10^6
6	6.5×10^7	2.2×10^7	TNTC	TNTC	2.1×10^4	4.7×10^4	2.0×10^6
10	5.0×10^7	3.2×10^7	TNTC	TNTC	2.8×10^5	5.3×10^4	2.5×10^6
20	5.2×10^7	-	TNTC	TNTC	3.1×10^5	6.5×10^4	3.1×10^6
40	4.3×10^7	0.7×10^7	TNTC	TNTC	3.2×10^5	8.2×10^4	1.5×10^6
60							1.5×10^6
				Unexposed Density	3.4×10^7	1.7×10^7	2.7×10^7

Note: Suspended Solids = 135 mg/l

[a] Coliform densities colonies/100 ml
[b] Exposure to UV
[c] Too numerous to count

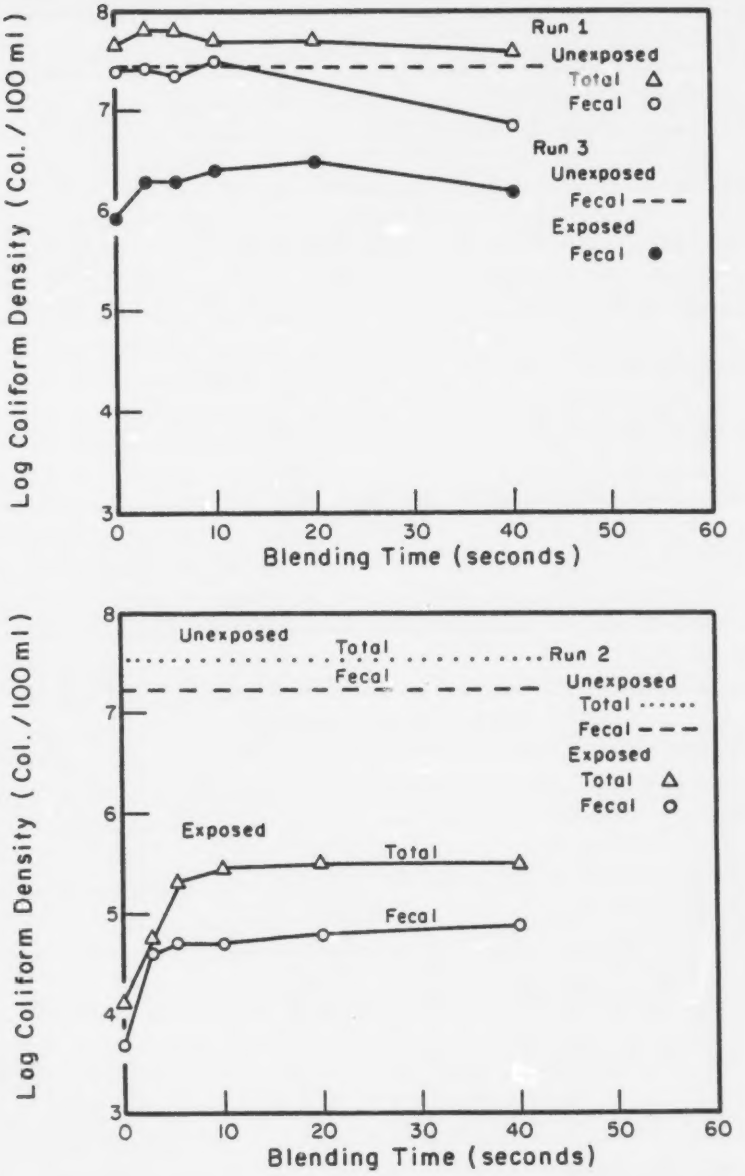

Figure 5-2. Effect of blending on the recovery of coliform from primary effluent samples.

The enumeration of the exposed blended samples was not successful. The results of the unexposed sample analysis indicate that blending did not yield significantly different recoveries. The tests were repeated in Runs 2 (August 24, 1981) and 3 (August 26, 1981); the results are also presented on Table 5-2 and on Figure 5-2. Blending was found to increase recoveries of the exposed samples. A blending time of 15 to 25 seconds was found to yield the maximum fecal coliform concentration for the exposed samples. Based on these results, a protocol was established to blend all primary effluent samples (exposed and unexposed) immediately before enumeration of total and fecal coliforms.

ANALYTICAL SCHEDULES

Each of the three units was normally sampled three or four days per week with one to four samplings taken per day. When not being sampled, the units were operated in a standby mode (lamps on and low flow), unless maintenance or repairs were necessary or if plant conditions did not allow operation of the units. During periods when one or more banks were off for sampling, those banks usually remained on when the units were not being sampled. Only two banks of lamps were operational in Units 1 and 2 from July through September 1983. Flow to the teflon unit was restricted to one channel for most of the experimental program and only lamps affecting that channel were operated.

The analytical schedules which were followed during the different periods of the experimental program are presented in Table 5-3. Exposed samples (UV effluent) were analyzed only for total and fecal coliforms during the entire program. During the first period (December 1, 1981 to March 7, 1983), each influent sample was evaluated for all parameters except the nitrogen series, which was done only one day per week. The analytical schedule for the second period (March 8, 1983 to April 21, 1983) was the same except for the nitrogen series; these had been eliminated for the rest of the experimental program as part of a program scope adjustment. During the third period (April 25, 1983 to August 25, 1983), the frequency of the COD and TOC analyses was reduced to one sample per day. The frequency of all other analyses remained the same as in the previous period. The analytical schedule for the final phase (August 30, 1983 to September 8, 1983), was identical to the third; however, only primary effluent samples were collected during this period.

TABLE 5-3 UV DISINFECTION PROJECT ANALYTICAL SCHEDULE

	Operational Period[(a,b)]			
Parameter	December 1, 1981 to March 7, 1983	March 8, to April 21, 1983	April 25, to August 25, 1983	August 30, to September 8, 1983
Total Coliform	I/E	I/E	I/E	I/E
Fecal Coliform	I/E	I/E	I/E	I/E
UV Absorbance				
Direct Total	I	I	I	I
Direct Filtered	I	I	I	I
Sphere Total	I	I	I	I
Sphere Filtered	I	I	I	I
COD				
Total	I	I	I (36%)	I (22%)
Filtered	I	I	I (36%)	I (22%)
SS	I	I	I	I
Turbidity	I	I	I	I
pH	I	I	I	I
Temperature	I (once/day)	I (once/day)	I (once/day)	I (once/day)
TKN				
Total	I (30%)	None	None	None
Filtered	I (30%)	None	None	None
NO_2-N	I (30%)	None	None	None
NO_3-N	I (30%	None	None	None
Sampling (% of total)	68%	10%	17%	5%
Primary Effluent	Special Studies	Special Studies	None	Every Sampling
Photoreactivation	None	None	Special Studies	None

[a] I - Influent
E - Effluent
[b] (-%) = percent analyses conducted, out of total number of samples

The approximate distribution of samples for each period are also presented in Table 5-3. There was a total of 513 samplings taken. A sampling comprised an influent sample and the effluent sample from one, two, or three units. Photoreactivation studies were conducted on selected samplings in July and August 1983. Samples of primary effluent were taken whenever possible during each of the first three periods. During the fourth period, all samplings were with primary effluent.

ANALYTICAL PROCEDURES

The procedures used in the analysis for the bacterial and wastewater parameters followed those described in Standard Methods(11) and/or the USEPA(12) unless otherwise noted.

Comparison of MF and MPN Procedures

There is evidence that the direct membrane filter (MF) technique will not yield full recovery of organisms that have been environmentally stressed.(13) This is thought to be due to the immediate use of a selective medium versus the non-selective nutrient broth used in the first 24 hours by the most probable number (MPN) method. This has been shown to occur with chlorinated effluent and special enrichment procedures are used to improve the method recovery. Since little information existed in this regard for UV exposure, a comparison was done of the MF and MPN procedures for enumerating coliforms. The direct MF procedure for total coliforms was followed. Plates were incubated for 24 ± 2 hours in a Fisher air incubator. The incubator temperature was maintained at 35 ± 0.5°C. The USEPA direct membrane procedure for fecal coliforms was followed. The plates were placed in Whirl Pack bags in a Blue M constant temperature water bath for 24 ± 2 hours. The temperature of the water bath was maintained at 44.5 ± 0.2°C.

The M-Endo agar for the total coliform and the MF-C agar for the fecal coliform were prepared following USEPA procedures. Disposable 60 x 15 mm plastic dishes and Gelman GN-6 presterilized filters were used.

Five dilutions with five tubes of lactose broth per dilution were set for the MPN presumptive test. After 24 ± 2 hours of incubation in an air incubator at 35 ± 0.5°C, positive tubes were transferred into brilliant green lactose bile broth for the confirmed test for total coliform and into EC medium for the fecal coliform confirmed test. The lactose tubes that were negative after 24 hours were incubated for an additional 24 hours; after 48 hours, any positive tubes were transferred for the confirmed tests.

The brilliant green lactose bile tubes were incubated at 35 ± 0.5°C for 24 ± 2 hours and checked for gas formation. Negative tubes were reincubated until a total incubation time of 48 ± 3 hours had elapsed and checked once again. The innoculated EC tubes were incubated in the Blue M constant temperature (44.5 ± 0.2°C) water bath for 24 ± 2 hours and then checked for gas formation.

Two 300 ml samples of secondary effluent (prior to chlorination) were placed in black opaque beakers. One beaker was constantly mixed with a magnetic mixer during a two minute exposure to UV light. After exposure, the beaker was covered with aluminum foil and completely mixed samples taken for duplicate total and fecal MF and MPN analyses. The second beaker was exposed to UV for four minutes following the same procedure. This was considered to be one replicate. Five more replicates were done, one per day and each with an effluent sample collected that day. The order of exposure was varied from replicate to replicate as was the order of analyses within each method. Three replicates were also done at one and three minute exposure times following the same procedures as above. The results of both series of replicates are presented in Table 5-4.

A three way analysis of variance was done on both the total and fecal coliforms for the two and four minute replicates (the conduct of one replicate series was questionable and not included in the data analysis).

A three-way analysis of variance was done for the five 2 and 4 minute replicates. The results are summarized in Table 5-5. Three main effects, (dose, method and replication) and four interaction effects, (replication-dose, replication-method, dose-method, and replication-dose-method) were considered for both total and fecal coliforms.

For both the total and fecal analyses all interactions are insignificant at the one percent level. The dose and replication main effects are significant for both total and fecal coliforms. At the one percent level of significance, method (MF versus MPN) is insignificant for fecal coliforms; however, the analysis indicates that method is marginally significant for total coliform.

TABLE 5-4 COMPARISON OF MF AND MPN PROCEDURES

Replicate	Exposure	Total MPN (MPN/100 ml)	Total MF (org/100 ml)	Fecal MPN (MPN/100 ml)	Fecal MF (org/100 ml)
1A	2 min	79	480	49	80
	2 min	350	510	33	40
	4 min	49	60	2	10
	4 min	17	110	2	10
	0	9.2×10^6	3×10^7	1.6×10^6	3×10^6
2A	2 min	11,000	21,000	2,200	1,060
	2 min	7,900	25,000	700	1,000
	4 min	4,900	7,000	170	1,130
	4 min	54,000	12,000	1,700	610
	0	1.6×10^7	3.6×10^7	1.6×10^6	7.3×10^6
3A	2 min	1,600	1,600	70	110
	2 min	1,600	1,600	110	210
	4 min	920	300	2	<10
	4 min	92	320	2	20
	0	3.5×10^6	1.9×10^7	1.3×10^6	6.2×10^6
4A	2 min	710	1,030	220	300
	2 min	1,100	1,230	350	380
	4 min	49	160	7	20
	4 min	22	160	11	30
	0	2.4×10^7	2.4×10^7	3.5×10^6	5.3×10^6
5A	2 min	790	1,240	140	300
	2 min	460	1,460	170	215
	4 min	33	130	23	35
	4 min	79	120	23	15
	0	2.4×10^7	3.0×10^7	3.5×10^6	7.4×10^6
1B	1 min	2,400	1,540	490	490
	1 min	1,100	4,550	260	555
	3 min	790	250	170	155
	3 min	330	1,040	110	420
	0	$\geq 2.4 \times 10^7$	2.4×10^8	9.2×10^6	1.6×10^8
2B	1 min	92,000	61,000	54,000	11,600
	1 min	92,000	79,000	35,000	7,400
	3 min	2,800	2,500	330	1,000
	3 min	1,100	12,400	790	4,450
	0	1.1×10^7	4.2×10^7	1.7×10^6	1.8×10^7
3B	1 min	$\geq$240,000	128,000	160,000	54,600
	1 min	$\geq$240,000	108,000	92,000	40,600
	3 min	7,900	15,800	1,100	2,630
	3 min	4,900	17,400	1,400	860
	0	1.3×10^7	4.2×10^7	1.7×10^6	7.3×10^6

TABLE 5-5 ANALYSIS OF VARIANCE SUMMARY FOR COMPARISON OF MF AND MPN PROCEDURES

Total Coliform Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F(Calc)
Replication	29.49	4	5.12	63.72
Dose	5.67	1	5.67	70.53
Method	0.69	1	0.69	8.52
Replication x Dose	1.38	4	0.35	4.30
Replication x Method	0.33	4	0.08	1.04
Dose x Method	0.0001	1	0.0001	0.0012
Replication x Dose x Method	0.37	4	0.09	1.11
Error	1.61	20	0.08	

Fecal Coliform Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F(Calc)
Replication	14.89	4	3.72	20.70
Dose	9.4	1	9.41	52.31
Method	0.54	1	0.54	3.01
Replication x Dose	1.60	4	0.40	2.23
Replication x Method	0.35	4	0.09	0.48
Dose x Method	0.48	1	0.48	2.70
Replication x Dose x Method	0.21	4	0.05	0.30
Error	3.60	20	0.18	

	Analysis of Variance - 3 Replicates 1 and 3 Minute Doses			
Total Coliforms Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F(Calc)
Replication	11.052	2	5.53	84.09
Dose	6.95	1	6.95	105.83
Method	0.084	1	0.084	1.28
Replication x Dose	0.69	2	0.35	5.29
Replication x Method	0.018	2	0.009	0.14
Dose x Method	0.22	1	0.22	3.30
Replication x Dose x Method	0.27	2	0.13	2.04
Error	0.79	12	0.066	

Fecal Coliform Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F(Calc)
Replication	10.66	2	5.33	29.65
Dose	7.65	1	7.65	42.55
Method	0.0005	1	0.005	0.003
Replication x Dose	1.98	2	0.99	5.49
Replication x Method	0.15	2	0.074	0.41
Dose x Method	0.59	1	0.59	3.26
Replication x Dose x Method	0.36	2	0.18	1.01
Error	2.16	12	0.18	

$$F(\text{Calc}) = \frac{\text{Mean Sq}}{\text{Error Mean Sq}}$$

F(1,20) = 8.10 at 1% level of significance
F(4,20) = 4.43 at 1% level of significance
F(1,12) = 9.33 at 1% level of significance
F(2,12) = 6.93 at 1% level of significance

A similar three-way analysis of variance was also done for the three 1 minute and 3 minute total and fecal coliform replicates. These results are also summarized in Table 5-5. At the one percent level of significance all interactions are insignificant for both total and fecal coliforms. The method main effect is insignificant at the one percent level for both total and fecal coliform while the dose and replication main effects are significant.

The dose main effect would be expected to be significant since a higher kill is expected at higher doses. The significance of the replication main effect is also expected since a different effluent sample was used for each replicate and effluent quality varies from day to day. Comparing methods for all replicates, the results suggest the differences in methods are not significant despite the fact that the method main effect for total coliforms with five replicates was marginally significant ($F_{calc} = 8.52$, $F_{statistic} = 8.10$).

Based on this limited series of tests, it was decided that the differences in the MF and MPN methods were not significant and that the recoveries are equivalent for the exposed samples. Analysis procedures were set to use the single step direct membrane filter technique.

Total and Fecal Coliform

Total and fecal coliform densities were determined in all cases by the MF technique as described in the preceding discussion. Four dilutions were routinely set for both influent and effluent total and fecal coliforms. Samples were split prior to making dilutions and set in duplicate beginning in May 1982. Prior to this random samples were selected and set in duplicate. At the start of each sampling day, the millipore setups were sterilized in a UV sterilizer (Millipore).

All MF media were prepared at HydroQual's laboratory (General Testing Corporation) in Hackensack, New Jersey, following USEPA procedures and shipped to Port Richmond. Plates, dilution bottles and tubes, and rinse water were also prepared at General Testing and transported to Port Richmond. All materials were stored at Port Richmond according to USEPA procedures.

Incubator temperatures were recorded daily when in use and adjusted as necessary. From mid-summer 1983 to the end of the experimental program, MSI presterilized filters were used in place of the Gelman GN-6 filters. All plates were set and incubated at Port Richmond within two hours after sampling. Plates with acceptable counts were averaged to give the colonies per 100 ml recorded for each influent and effluent sample.

Filtrations--

Filtrations necessary for analysis of the soluble component of each influent sample were done at Port Richmond using Gelman A/E glass fiber filters under 38-50 cm of vacuum.

UV Absorbance--

The UV absorbance at 253.7 nm was measured with a Perkin Elmer 552A-UV Visible Scanning Spectrophotometer, using a deuterium lamp as a light source. Measurements were made with 1 cm path length quartz cells. Absorbance units per centimeter (a.u./cm) were read directly from the instrument readout. This reading was converted to percent transmittance using the expression:

$$\%T = 100 \times 10^{-(a.u./cm)}$$

The absorbance in base e is what is referred to in the report as the absorbance coefficient and is computed as:

$$\text{Absorbance Coefficient} = 2.3\ (a.u./cm)$$

The single beam spectrophotometer measurements described above are referred to herein as the "direct" UV absorbance. A second absorbance measure was also taken utilizing a Perkin-Elmer Integrating Sphere (No. B010-3751) inserted into the UV-Vis spectrophotometer. This accessory accounts for light which is scattered by particulates suspended within the sample and gives a better representation of the "true" absorbance of the sample. The standard single beam spectrophotometer implicitly measures scattered light as absorbed light. The corrected absorbance measure is referred to as the "spherical" absorbance.

Chemical Oxygen Demand (COD)--

The COD analyses were performed by the dichromate reflux method per Standard Methods.

Total Organic Carbon (TOC)--

TOC was measured by an Oceanography International Model 0524B-HR Total Organic Carbon Analyzer.

Suspended Solids--

Suspended solids were determined using Gelman A/E glass fiber filters. The filtered residue was dried in a 103°C oven overnight. All suspended solids analyses were conducted at the Port Richmond laboratory.

Turbidity--

Turbidity measurements were made with a Hach HF Turbidity Meter which was calibrated at each use with a prepared 4.0 or 40 NTU standard (depending on the turbidity range of the samples).

pH--

The pH was determined with a Corning pH meter and a Ross Combination pH electrode. The meter was calibrated at each use with buffers of pH 4.0, 7.0 and 10.0.

Temperature--

Wastewater temperature was measured in the influent tank once per day using a general laboratory thermometer.

Total Kjeldahl Nitrogen, Ammonia Nitrogen, Nitrite Nitrogen, Nitrate Nitrogen--

The nitrogen series was run using automated procedures. Samples were analyzed for TKN using an automated phenate method with a Technicon BD-40 block digester and Technicon II Autoanalyzer. Ammonia nitrogen samples were analyzed by an automated phenate method using a Technicon II autoanalyzer. An automated diazotization method with a Technicon I autoanalyzer was used for nitrite analyses. Nitrate analyses were done with a Technicon I autoanalyzer using an automated brucine method.

SPECIAL STUDIES

Hydraulic Evaluations

A series of tests were performed to define the time distribution and flow characteristics through each of the submerged quartz systems (Units 1 and 2). Prior to this, each unit had been evaluated to determine if there existed an acceptable approach condition, i.e., no shortcircuiting or significant velocity gradients across the front plane of the lamp battery. Significant gradients were found, particularly on the widely spaced unit (Unit 2). This was due (on both units) to the position of the inlet pipe and the relatively small size of the influent tank. Sufficient time and volume were not available to dissipate and equalize the velocity before entering the lamp battery. An overflow weir and stilling wall were subsequently installed in each influent tank to correct this problem. Further tests and observations indicated a good flow distribution across the plane of the lamp battery, with no evidence of shortcircuiting.

Mixing characteristics within each UV unit were evaluated using real time measurements of conductivity. Salt (NaCl) was used as the tracer. The normal procedure for developing detention time curves, i.e., taking discrete samples after an instantaneous tracer injection, was not possible given the system design at Port Richmond. The theoretical detention times (V_v/Q) were between 2 and 30 seconds leaving little time to practicably inject a sufficient quantity of tracer and collect an adequate number of samples to construct the trace. Additionally, the design essentially simulates an open channel with the lamp battery inserted across the width of the channel, making it very difficult to take representative discrete samples.

A new procedure was developed, as shown schematically on Figure 5-3. A concentrated salt solution was injected at a constant rate at a selected location immediately in front (approximately 3.8 cm) of the lamp battery. A conductivity probe was used to search for the point of maximum concentration on the exit side of the lamp battery. Note that the probe was also used to scan the entire exit plane in order to define the conductivity profile and location of the plume as it exited from the lamp battery.

Once the probe was situated and fixed at the center of the plume, a steady state condition was allowed to develop at fixed wastewater and salt solution flow rates. The high frequency output from the conductivity meter was amplified and continuously recorded using an oscillograph. Continuous permanent tracings were made by a light beam onto light sensitive recording paper advancing at a rate of 0.64 cm/second. The recorder/meter was first calibrated by measuring the conductivity of known salt solutions. The Port Richmond wastewater has a very high conductivity due to significant saltwater inflow to the collection system. Because of this high background conductivity, it was not possible to use actual secondary effluent for the studies. The tests were conducted with clean water by piping potable water from a nearby hydrant to the head tank.

Once steady state was indicated by the recorder, the salt solution pump was shut-off. This event was automatically signalled to the oscillograph and recorded. The die-away of salt was then monitored by the fixed probe and continuously recorded. Readings (conductivity) were then taken off the trace, converted to salt concentration (mg/1), and transposed to a plot of concentration against time.

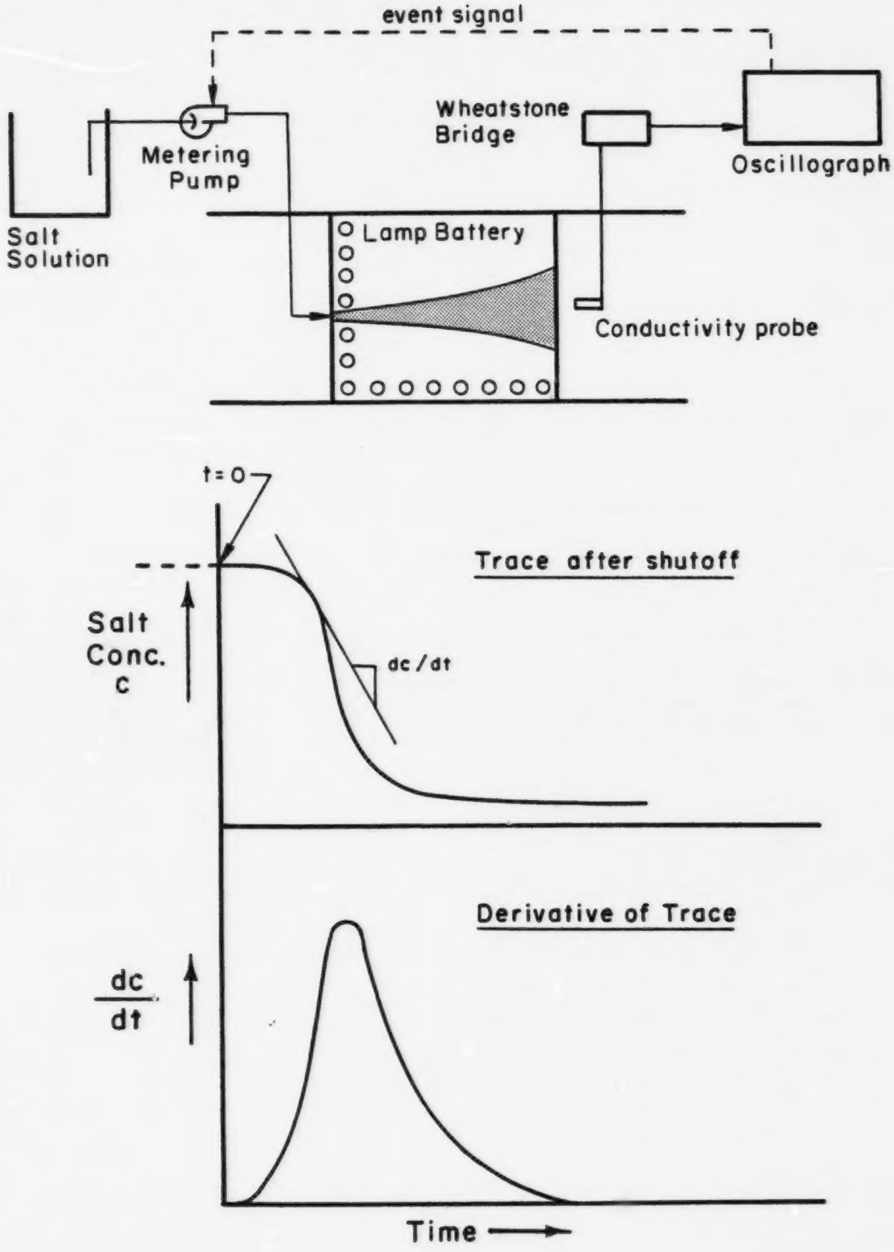
event signal
Metering Pump
Wheatstone Bridge
Oscillograph
Salt Solution
Lamp Battery
Conductivity probe
t=0
Trace after shutoff
Salt Conc. c
dc/dt
Derivative of Trace
dc/dt
Time

Figure 5-3. Experimental setup and analysis technique for retention time studies.

Figure 5-3 also presents the graphical method used to analyze the resulting trace. The upper plot shows concentration against time. These data were interpreted from the oscillograph recording and conductivity-salt concentration calibration. The derivative of this curve is taken by plotting the slope (dc/dt) of tangents drawn at several locations along the curve. This is shown on the lower plot and resembles the typical curve derived from an impulse release.

Head Loss

The head loss associated with the lamp batteries was measured in Units 1 and 2, by measuring the water level height differential between the inlet and outlet bulkhead plates. This was repeated over the range of operational flows for the two units.

Cleaning as a Maintenance Task

Units 1 and 2 were disassembled and thoroughly cleaned three times during the experimental program (February 1982, February 1983, and July 1983). Each lamp was removed from the unit and wiped with soapy water and then wiped with alcohol. The inside of each quartz tube was also wiped with soapy water followed by alcohol using a cleaning rod supplied by the manufacturer. The outer surfaces of the quartz tubes were cleaned following the routine acid/detergent cleaning procedures.

Several methods of cleaning the teflon tubes in Unit 3 were tried. Concentrated sulfuric acid was pumped into the effluent tank and recirculated through the unit for approximately one hour with a Jabsco centrifugal pump. The unit was then flushed out at a high flow. The same procedure was followed using oxalic acid and also sulfuric acid with detergent. The use of a plumbers snake with a cloth to clean the acidified tubes was also evaluated. None of the above in-place cleaning methods provided satisfactory results.

The teflon unit was overhauled February 1983. All lamps were wiped with soapy water and then wiped with alcohol. The teflon tubes in two channels were replaced with new ones. ENERCO developed a high pressure detergent cleaning procedure for the teflon tubes which was tested towards the end of the study. This method involved snaking a hose down the tube with a high pressure spray nozzle at the end. Using clean water appeared to be adequate (in this case the system does not have to be taken out of service). There is also the ability to educt a detergent solution into the high pressure water stream.

Photoreactivation

Photoreactivation studies were performed on selected samplings in July and August 1983. At each sampling where photoreactivation was evaluated two additional effluent samples would be taken per unit during the routine sampling sequence. One of the extra samples was taken in a clear glass bottle (light bottle) and the other in a black opaque bottle (dark bottle). These bottles were then suspended in a water bath (an approximately 760 liter plastic tank) and exposed to visible light (ranging from full sun to overcast) for one hour. Samples from each bottle were then analyzed for total and fecal coliform density. These results were then compared to the coliform densities measured immediately after UV exposure.

Lamp Rating

Several tests were conducted during the experimental program to estimate the total output of selected lamps at 253.7 nm. These studies were typically done with and without the quartz sleeve in place.

The test procedure closely follows that described by Johnson and Qualls.(14) A lamp was mounted in brackets with a 122 cm length of string attached to the bracket mount at the midpoint of the lamp. The IL 570 detector was placed at the end of the string, always pointed at the centroid of the lamp. A protractor was mounted in such a way that the string with the detector mounted at the end was at the 90° point. The detector was then moved at 15° intervals from 15° to 165° and the intensity recorded.

The UV power of the lamp was then calculated by integrating the intensity measurements over the surface of a sphere scribed by the radial distance of the detector to the lamp center. In effect, this technique treats the lamp as a point source. By comparing the power with and without the quartz tube an estimate of the percent transmitted through the quartz was made. The power of a lamp being used in the units was also compared to the power of a new lamp.

Lamp Aging

In May 1983, the intensity of each lamp was measured to determine the UV output relative to a new lamp, and hence the effects of aging. In the same manner as discussed above, each lamp was clamped between two ringstands and the IL 570 recorder positioned 122 cm from the midpoint of the lamp. The intensity was recorded for each lamp in this manner, after a three minute warmup time. One hundred lamps were replaced with new lamps at this time relamping the two operating tanks of the unit. The same procedure of checking output was then repeated at the conclusion of the experimental program in September 1983.

Quartz Fouling

The effect of quartz fouling on intensity was determined by an experimental setup similar to that used for lamp aging. Units 1 and 2 were acid/detergent cleaned and six quartz tubes were removed from one of the units. Using a new lamp, the intensity was measured at a fixed point, 122 cm from the center of the lamp, after a three minute warmup time. This was repeated with each of the quartz sleeves placed over the lamp. The inside of each quartz tube was then cleaned with soapy water followed by an alcohol wipe. Intensities were measured once again. Finally, the outside of the tubes were cleaned with soapy water followed by an alcohol wipe, and the intensities recorded. Intensities were also recorded with a new quartz tube.

Dosimetry

Several dose-response studies were done during the project using a collimated beam procedure similar to that described by Johnson and Qualls.(14) A 15 watt UV lamp was clamped between two ringstands and all but a portion of the lamp shielded. A column (either 30.5 or 53.8 cm long), the inside of which had been painted a flat black, was clamped below the exposed portion of the lamp. The size of the exposed portion of the lamp varied from 5.1 to 7.8 cm, depending on the column used. A known volume of secondary effluent sample was placed below the column and exposed to the UV light. The light, by having to pass through the column, was assumed to be reaching the water surface perpendicular to the surface. Its intensity at the water surface could then be accurately measured by the IL 570 detector. Samples were constantly mixed with a magnetic mixer during exposure. At the beginning and end of each series of runs, the intensity at the liquid surface was measured using the IL 570 radiometer.

The influent sample was split prior to the UV exposure on a number of the dosimetry runs; one aliquot was centrifuged for 10 minutes at low speed in sterilized centrifuge tubes and the supernatant was subsequently exposed to UV. The other half was exposed without centrifuging. Samples were typically taken at exposures of 0, 60, 120, 240, 360 and 0 seconds, in sequence. Fecal coliform densities were determined using the MF procedure. The samples were also analyzed for COD, suspended solids, turbidity and UV absorbance.

SECTION 6

DEVELOPMENT OF UV DISINFECTION MODEL

INTRODUCTION

A major objective of the Port Richmond project was to develop a uniform and rationally based procedure by which a UV system can be designed and evaluated. Typically, full-scale design approaches have been empirically based, relying on limited pilot data, manufacturers' bioassay performance data, or on previous full-scale operating experience. This is not to say that systems that are now in place are not properly sized; most are in fact conservatively designed. The lack of a rationally based approach, however, inhibits the ability to optimize the process design of a system and to understand the sensitivity to critical design parameters. The empirical approach also constrains the ability to troubleshoot a system which is not performing to its design standards.

Rationally based procedures rely on a clear understanding of the basic mechanisms by which a process works. These can be described mathematically and are applicable regardless of the particular configuration about which the process is designed. As an example, the mathematical expressions of time, intensity and the effects of UV on microorganisms must hold (if they are developed correctly) regardless of how a particular UV system is configured. The rational bases of the design must incorporate the physical and kinetic elements which will affect the specific process performance.

This does not preclude the need for actual data from bench, pilot, or full-scale evaluations. The mathematical approach allows us to evaluate these data and also provides a clear understanding of the type of information which must be collected. This combination provides a powerful design tool in optimizing the system and understanding the sensitivity of the design to a matrix of operating and wastewater conditions which cannot be practically addressed in a limited field study.

Linking the mathematical expressions which describe the mechanisms and variants of a process to a single (or series of) mathematical expression is a mathematical model. The development of such a model was a primary objective of the Port Richmond project. The following discussions present the basic mechanisms of UV disinfection and the framework about which the UV disinfection process is modeled. Subsequent sections discuss the application of the model to design, based on the results of the Port Richmond field program.

UV DISINFECTION PROCESS

Inactivation of microorganisms by light energy in the UV range has been studied extensively and is well documented. The inactivation is primarily the result of the energy being absorbed by the genetic material of an organism, deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). The primary cause of the lethal and mutagenic effects are the formation of thymine dimers. These cause distortions in the DNA that prevent the proper replication of DNA strands, resulting in death, mutation of offspring, and in inviable offspring.

Most microoganisms have the ability to repair UV induced damage. The most prevalent mechanism is by photoreactivation, a photoenzymatic repair or reversal of the UV induced dimerization. This will occur upon exposure to longer wavelength light energy in the visible range. A second repair mechanism is the so-called "dark repair" whereby the damaged area on the DNA strand is enzymatically excised. The sensitivity of an organism to UV inactivation is often related directly to the organism's ability to subsequently repair the damage.

Organisms can be inactivated by shortwave UV if the energy is absorbed in sufficient quantity by the organism's genetic material. Thus, the peak absorbance of the DNA and RNA molecules coincides with optimum wavelengths for germicidal activity. This wavelength has a range between 250 and 270 nm, with the maximum effectiveness occuring near 260 nm. As a consequence, the low pressure mercury arc lamp, which has its maximum output at 253.7 nm, has gained nearly universal acceptance as the source of germicidal UV light.

UV PROCESS DESIGN

The inactivation of bacteria can be described by the first order expression:

$$L = L_o \exp[-kIt] \tag{6-1}$$

where:

L = bacterial density after exposure to UV (org/L^3)
L_o = the initial bacterial density (org/L^3)
k = rate constant (T^{-1})
I = the intensity of the germicidal UV energy (Watts/L^2)
t = time of exposure (T)

Intensity is an expression of the rate at which energy is being delivered. In the context of this report, intensity will have the units microwatts per square centimeter (μWatts/cm^2). (Understand that a Watt is joules/second; thus, the time element for the rate of delivery is contained in the term Watt.) By multiplying by the time to which an entity is exposed to this rate, the quantity of energy, or dose, is determined:

$$\text{Dose } (\mu\text{Watt-sec/cm}^2) = \text{Intensity } (\mu\text{Watt/cm}^2) \times \text{Time (seconds)}$$

The rate constant, k, is the slope of the relationship of ln L/L_o as a function of the dose. It is generally held that intensity and time are reciprocal in their effect on the dose.

Although the first order expression is generally a good first approximation of the response to a given dose, direct testing on either pure or mixed cultures often results in evidence of a tailing effect. This is attributed in most cases to the aggregation of the bacteria or the occlusion of the bacteria in particulate matter.(6,15) The UV light is unable to penetrate this material and affect inactivation of the bacteria. Thus, as the dispersed or singlet bacterial organisms are inactivated, continued elevation of the dose will show a diminishing response as the residual active bacteria are protected in the particulates.

It is apparent from the definition of dose that the two key design parameters for disinfection by UV are the intensity and the time to which the organism is exposed to this intensity. The consequent design objective can then be best described as providing a system which maximizes utilization of the delivered energy (i.e., minimizes the loss of energy) and allows the necessary exposure time for each organism contained in the wastewater. A constraint on the performance of the system will be the limiting residual density attributable to the particulates contained in the wastewater. Clearly understanding the impact and the design considerations relating to these three factors will allow for an effective and optimal system design.

PROPOSED UV DISINFECTION MODEL*

The mathematical model proposed for the UV disinfection process is rooted in the estuarine water quality approaches described by Thomann.(16) Consider the UV reactor shown on the upper display of Figure 6-1, with its length along the x-coordinate and its height and width along the y and z coordinates, respectively. This is analogous to a river where the x coordinate is along the river's length. In such a system it is reasonable to assume that the wastestream (river) is homogenous with respect to water quality in the y-z plane and will vary only along the x-axis, i.e., the system is one-dimensional.

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*See Appendix C for analysis of model development.

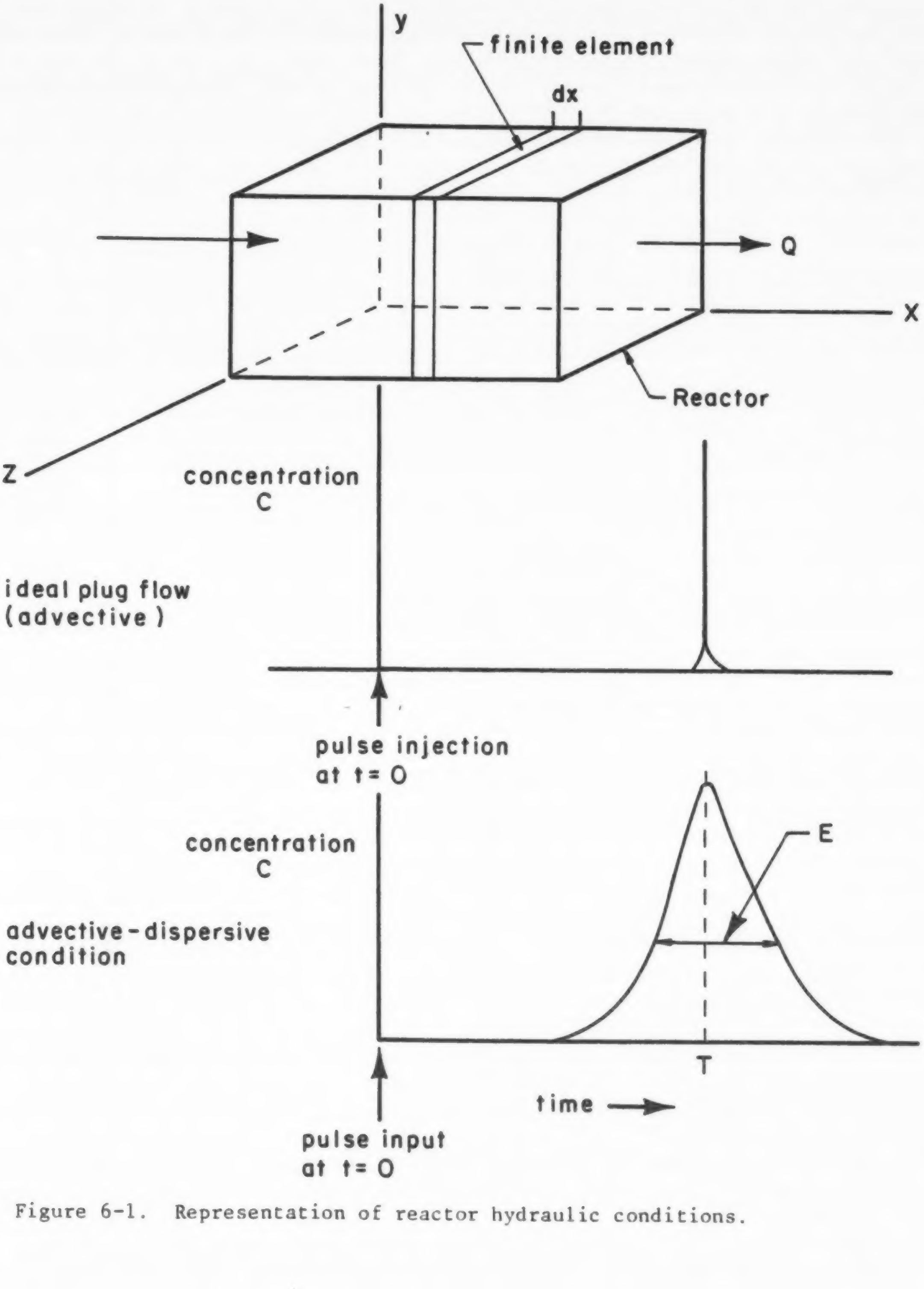

y
finite element
dx
Q
X
Reactor
Z
concentration C
ideal plug flow (advective)
pulse injection at t= 0
concentration C
E
advective-dispersive condition
T
time
pulse input at t= 0

Figure 6-1. Representation of reactor hydraulic conditions.

A deterministic model can be developed by constructing a mass balance about an elemental volume, V, representing a cross-sectional "slice" of the reactor. The volume is equal to the cross-sectional area, A, times the width of the finite slice, Δx.

Ideally, if a specific exposure time is required to achieve a desired degree of inactivation, then the correct design will allow each microorganism or element of water to realize this retention time in the UV reactor. In a dynamically flowing system this condition is termed ideal plug flow. Each element moves in the direction of flow in a discrete fashion without mixing due to diffusion or dispersion. This condition is schematically displayed on the middle panel of Figure 6-1, which shows the response to a pulse injection upstream from the point of observation. In the ideal plug flow case, the pulse discharge retains its identity as it moves downstream. The pulse would reach a point downstream instantaneously at the theoretical travel time, T, equal to x/u, where x is the distance downstream and u is the travel velocity. If the material is nonconservative, decay would occur as it travels, affecting only the magnitude of the peak at time T.

A mass balance about the element of the UV reactor over a time interval Δt can be written:

Change in Coliform Mass = Coliforms In - Coliforms Out - Coliform Loss

Assuming there are no sources or sinks of coliform other than decay (inactivation) within the element, the full equation is:

$$\underset{\text{(change)}}{V\Delta L} = \underset{\text{(input)}}{QL\Delta t} - \underset{\text{(output)}}{(Q + \Delta Q)\,\left(L + \frac{\partial L}{\partial x}\Delta x\right)\Delta t} - \underset{\text{(decay)}}{KVL\Delta t} \qquad (6\text{-}2)$$

dividing by Δt and knowing that $V = A\Delta x$,

$$\frac{\Delta L}{\Delta t} = -\frac{Q}{A}\frac{\partial L}{\partial x} - \frac{L}{A}\frac{\Delta Q}{\Delta x} - \frac{\Delta Q}{A}\frac{\partial L}{\partial x} - KL \qquad (6\text{-}3)$$

If the infinitesimally small terms approach zero the equation becomes:

$$\frac{\partial L}{\partial t} = -\frac{1}{A}\frac{\partial(QL)}{\partial x} - KL \tag{6-4}$$

This model, assuming no dispersion, is referred to as an advective model.

At steady state,

$$\frac{\partial L}{\partial t} = 0$$

and $L = L_o$ at $x = 0$

Q is constant in time, and A is a constant fixed by the dimensions of the reactor. Presuming the coliforms to be non-conservative, Equation (6-4) becomes:

$$0 = -\frac{Q}{A}\frac{dL}{dx} - KL \tag{6-5}$$

or

$$u\frac{dL}{dx} + KL = 0 \tag{6-6}$$

where u is the velocity. Integration yields:

$$L = L_o \exp\left[-\frac{Kx}{u}\right] \tag{6-7}$$

Thus, the coliform are seen to exponentially decay with distance through the reactor. This is similar to Equation (6-1); x/u is equivalent to the time, t. The rate coefficient, K, will be a function of the UV intensity within the reactor.

Under actual reactor conditions, this true plug flow may not exist. Dispersion and velocity gradients will cause the pulse discharge to spread as it moves downstream, as shown on the lower display of Figure 6-1. Thus, although the intention may be to achieve an exposure time, T, for all elements passing through the reactor, there is in fact a distribution of time about the ideal time. This distribution is a function of the dispersion characteristics of the reactor, which can be quantified by defining the spread of the time-distribution relationship graphically represented on Figure 6-1.

Dispersion can be incorporated into Equation (6-7) by again considering a mass balance about the elemental slice of the reactor. A dispersion term is included to account for the integrated effects of velocity and density gradients. The dispersion is assumed to occur in the direction of decreasing concentration gradients; thus, dispersion from the upstream face is negative and from the downstream face is positive.

The mass of coliforms entering the upstream face due to dispersion over a time interval is:

$$(- EA \frac{\partial L}{\partial x}) \Delta t$$

where E is defined as the dispersion coefficient in units (L^2/T). The downstream output due to dispersion is written:

$$- (EA + \Delta EA) [\frac{\partial L}{\partial x} + \frac{\partial}{\partial x} (\frac{\partial L}{\partial x}) \Delta x] \Delta t$$

These expressions can be incorporated into Equation (6-2) (right side). Subsequent manipulation then yields:

$$\frac{\partial L}{\partial t} = - \frac{1}{A} \frac{\partial}{\partial x} (LQ) + \frac{1}{A} [\frac{\partial}{\partial x} (EA\frac{\partial L}{\partial x})] - KL \tag{6-8}$$

At steady state, Equation (6-8) becomes:

$$0 = -\frac{1}{A}\frac{d}{dx}(LQ) + \frac{1}{A}\left[\frac{d}{dx}\left(EA\frac{dL}{dx}\right)\right] - KL \qquad (6\text{-}9)$$

Assuming $L = L_o$ at $x = 0$, and constant Q, E, and A, the expression is:

$$0 = -\frac{Q}{A}\frac{dL}{dx} + E\frac{d^2L}{dx^2} - KL \qquad (6\text{-}10)$$

for values of $x > 0$, the solution of Equation (6-10) is:

$$L = L_o \exp\left\{\frac{ux}{2E}\left[1 - \left(1 + \frac{4KE}{u^2}\right)^{1/2}\right]\right\} \qquad (6\text{-}11)$$

Equation (6-11) forms the basis for the proposed UV disinfection model. A review of the parameters is appropriate, therefore, at this point to relate it directly to the design of a UV system:

L = the bacterial density after exposure. This is typically coliforms (total or fecal) with the units MPN/100 ml or Organisms/100 ml.

L_o = the initial bacterial density, measured immediately before entry into the UV reactor.

x = the distance traveled by an element of water while under direct exposure to UV light, in centimeters. This is usually taken as the length of the lamp battery in the direction of flow. If a serpentine flow pattern is created by internal baffling an "effective" x will need to be determined.

u = the velocity of the wastewater through the UV reactor (cm/second). This is calculated as

$$x/\left(\frac{V_v}{Q}\right)$$

where V_v is the void volume of the UV reactor (liters) and Q is the total flow (liters/second).

E = the dispersion coefficient (cm^2/second). E can be approximated from the time-distribution curve of a particular system.

K = the rate coefficient for inactivation of coliforms (sec^{-1}).

The parameters L_o, u, and x are set by the wastewater characteristics and the physical configuration of the UV reactor. The dispersion coefficient, E, will be a function of the physical design of a system. Subsequent sections discuss the methods used for approximating E for the systems at Port Richmond.

The inactivation rate coefficient will be a function of the intensity with which a particular reactor can deliver the germicidal UV energy:

$$K = f(I)$$

An estimation of this rate will, therefore, require knowledge of the actual intensity levels within the UV reactor. This is not a straightforward procedure. Subsequent discussions will present calculation techniques used for the Port Richmond units to estimate the average intensity.

Equation (6-11) incorporates the elements of time and intensity in predicting the performance of the disinfection system. As discussed earlier the third critical element is the estimation of the coliform density attributable to the particulates in the wastewater. This is considered additive to the density predicted by the above expression and will likely be a site specific characteristic. Thus, Equation (6-11) now becomes:

$$L = L_o \exp \{\frac{ux}{2E} [1 - (1 + \frac{4KE}{u^2})^{1/2}]\} + L_{particulate} \qquad (6-12)$$

where $L_{particulate}$ is a function of some measureable index of particulate density in a wastewater, such as suspended solids or turbidity.

UV INTENSITY

As discussed earlier, the rate of disinfection is directly related to the intensity of UV light within the reactor. Thus, it is important that the intensity be quantified for a given system configuration. It will be a function of the UV source, the physical arrangement of the source relative to the wastewater, and the energy sinks present which will attenuate the source output before it can be utilized for disinfection purposes.

The UV source almost universally used for wastewater disinfection systems is the low pressure mercury arc lamp. These are long (typically 1 to 1.5 meters) thin cylinders (1.5 cm in diameter) which are typically arranged in symmetrical bundles with the lamps parallel to one another. In the quartz systems the lamps are sheathed in quartz sleeves and submerged in the wastewater to be disinfected. The direction of flow can be perpendicular or parallel to the lamps. In systems where the wastewater does not contact the lamp battery, the lamps are generally placed above the flowing liquid (as in the Kelly-Purdy design) or surrounding and parallel to a conduit which is carrying the fluid and is tranluscent to UV (e.g., the Enerco teflon design).

These complex lamp systems do not allow for the direct measure of the actual intensity at any point within the lamp battery. Current detector designs are planar, recording radiation perpendicular to the surface. Cosine correcting detectors will respond to a greater field of radiation, but they are still limited to measuring a planar surface. A microorganism moving through a complex lamp system will in fact be exposed to radiation from all directions; current detector systems are not capable of adequately measuring the intensity under such conditions.

A computational method has been developed which can approximate the light intensity within a system on the basis of the physical properties of the UV lamps, the configuration of the multilamp reactors, and the properties of the aqueous medium. The software developed during this project, named The Ultraviolet Light Intensity Program (TULIP) uses a point source summation technique to calculate light intensity at given distances from a line source emitter. The point source summation technique was described by Jacob and Dranoff(17) and was first applied to UV disinfection system design by Johnson and Qualls.(10)

Calculation Framework

The UV intensity will attenuate as the distance from the source increases. This attenuation occurs by two basic mechanisms: dissipation and absorption. Dissipation is simply the dilution of the energy as it moves away from the source. The area upon which the energy is being projected is increasing, thus the energy per unit area is decreasing. This dissipation can be calculated by surronding the source by a sphere of radius R:

$$I = S/(4\pi R^2) \tag{6-13}$$

where I is the intensity at a distance R in μWatts/cm^2, R is the distance in centimeters, and S is power available from the UV source in μWatts. Thus, dissipation is seen to attenuate the intensity as the inverse of the radius squared.

The second attenuation mechanism relates to the absorptive properties of the medium through which the energy is transmitted. This is best described by Beer's Law:

$$I = I_o \exp[-\alpha R] \tag{6-14}$$

where I_o is the intensity at a given surface on the source (watts/cm^2), α is the absorbance coefficient of the medium through which the energy is passing (cm^{-1}), and R is the distance at which I is measured relative to the point represented by I_o. The absorbance coefficient reflects the absorbance at the specific wavelength being emitted; in the case of the low pressure mercury arc lamps, the wavelength is 253.7 nm.

Combining Equations (6-13) and (6-14) yields an expression which describes the intensity at a given distance from a single point source of energy:

$$I = [S/(4\pi R^2)] \exp(-\alpha R) \tag{6-15}$$

This equation serves as the basis for the calculation technique. Two basic assumptions are also stipulated:

1. that the germicidal lamp can be considered a series of point sources,

2. that a receiver (i.e., a microorganism) passing through the reactor is infinitely small and is spherical; by this it can then be presumed that the energy emitted from any point source element of the lamp will strike the receiver normal to its surface.

The intensity at a receiver is then the summation of the intensities from each of the point source elements of a lamp, (or lamps in a multilamp system). Figure 6-2 is a schematic representation of this calculation. As shown, the intensity at the receiver location (r,z_o) is the summation of the intensities from each of the lamp elements:

$$I(r,z_o) = \sum_{n=1}^{n=N} \frac{S/N}{4\pi\,(r^2+z_n^2)} \exp\left[-\alpha(r^2+z_n^2)^{1/2}\right] \tag{6-16}$$

where N is the number of point source elements in the lamp. The value of z_n is:

$$z_n = z_o - L(n/N)$$

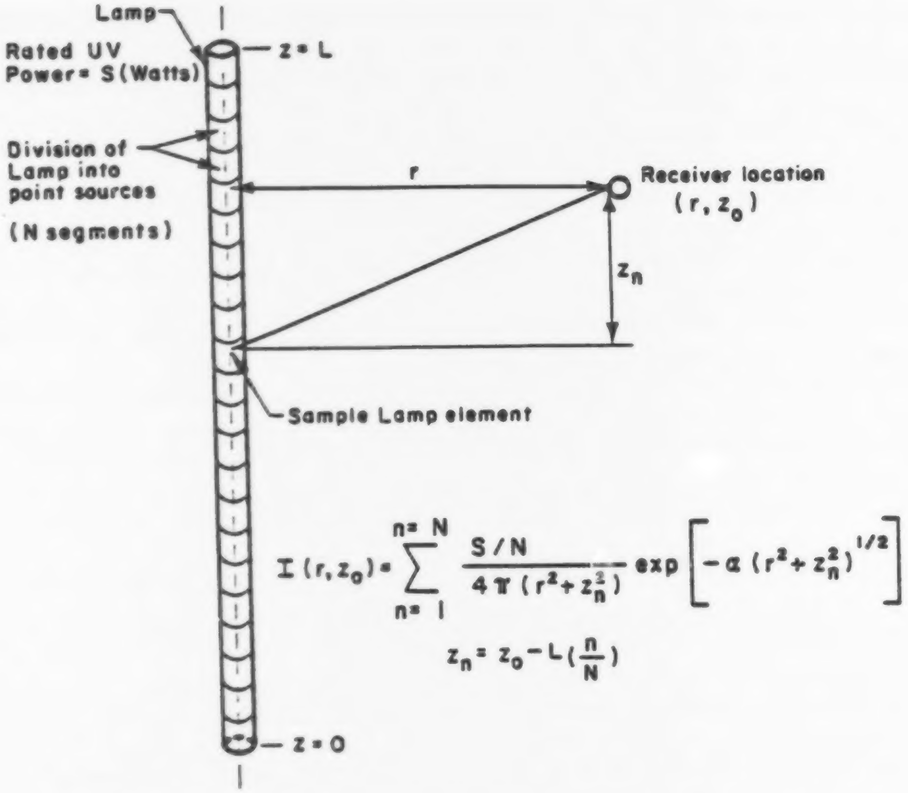

Lamp
Rated UV Power = S (Watts)
z = L
Division of Lamp into point sources
(N segments)
r
Receiver location (r, z_o)
z_n
Sample Lamp element
$I(r,z_o) = \sum_{n=1}^{n=N} \frac{S/N}{4\pi(r^2+z_n^2)} \exp\left[-\alpha(r^2+z_n^2)^{1/2}\right]$
$z_n = z_o - L\left(\frac{n}{N}\right)$
z = 0

Figure 6-2. Lamp geometry for point source approximation of intensity.

The computer program uses Equation (6-16) to calculate intensity at any given point from a UV lamp or lamps.

TULIP uses a simple technique to calculate the UV intensity at any given point (receiver) within a system. The point in space can be at a distance from a single bulb or oriented within a grid of any number of bulbs. The program will account for the effects of shading by other bulbs, or other energy sinks between the receiver and the bulb of interest.

A schematic diagram of a typical set of bulbs and a single receiver is shown on Figure 6-3. In order to calculate the UV intensity at a receiver located at x_r, y_r, and z_r, due to the bulb subelement located at x_{bs}, y_{bs},

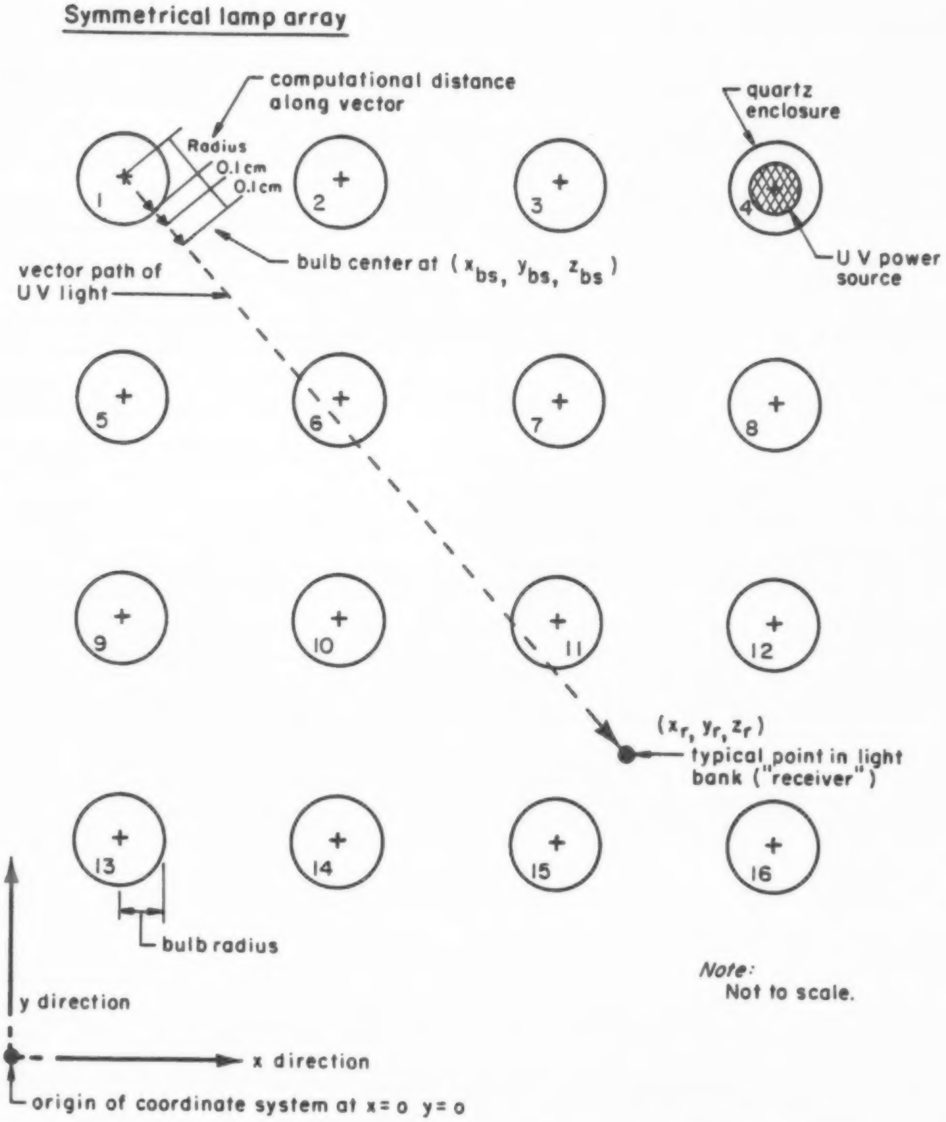

Symmetrical lamp array
computational distance along vector
Radius
0.1 cm
0.1 cm
quartz enclosure
bulb center at (x_bs, y_bs, z_bs)
vector path of U V light
U V power source
1
2
3
4
5
6
7
8
9
10
11
12
(x_r, y_r, z_r)
typical point in light bank ("receiver")
13
14
15
16
bulb radius
Note: Not to scale.
y direction
x direction
origin of coordinate system at x = o y = o

Figure 6-3. Schematic of computational technique for calculating intensity (typical profile view).

and z_{bs}, the program first connects a vector from the bulb subelement to the receiver. As shown, the vector passes through bulbs number 6 and 11 on a path from bulb number 1 to the receiver point. The loss of energy or shading caused by these intervening bulbs is accounted for by a specific absorbance coefficient. Its value would be determined by laboratory testing or from previous experience. In the case of the mercury arc bulbs, which are excellent absorbers of the UV light, the program is set to allow for total absorbance of energy striking a bulb which had been emitted by a neighboring bulb.

Computation of intensity at a receiver proceeds from the light emitting subelement to the receiver along the directional vector. In the case of the quartz systems, the intensity at the outer quartz surface is calculated, assuming the absorbance is equal to zero:

$$I = SP/(4\pi R^2) \tag{6-17}$$

Where I is the intensity in μWatts/cm^2, SP is the power of the bulb subelement (=S/N), and R is the distance from the bulb center to the outer surface of the quartz sheath in cm. Any losses incurred by passing through the quartz or by fouling of the surfaces can be accounted for by proportional adjustment of the I calculated at the quartz surface.

The program then takes finite steps along the vector. After each step, the new position is calculated in x,y, and z space. A check is then made to determine if the new point on the vector is within a bulb or is in the wastewater medium. If the point is within a bulb, the program assigns an absorbance coefficient equal to the input bulb absorbance coefficient (cm-1). If the terminal vector point is not inside the bulb an absorbance coefficient equal to that of the water is assigned. At this point, TULIP recalculates the UV intensity:

$$I_{new} = \frac{I}{(1 + \frac{dR}{R})^2} \exp\,[-\alpha dR] \tag{6-18}$$

I in this case is the intensity calculated from the previous step, α is the assigned absorbance coefficient (cm^{-1}), dR is the step size (cm) and R is the total distance from the bulb to the previous terminal point on the vector (cm).

The program then continues to step along the vector until the receiver is reached. At this point, the program has calculated the intensity at the receiver from one bulb subelement. The procedure is then repeated for each of the subelements of a bulb and for each of the bulbs in the system. The total intensity at the receiver is then the sum of all the subelement intensities.

The program uses a three-dimensional coordinate system. Figure 6-4 is a sample diagram of a typical UV light bank which is properly oriented in the coordinate system. A requirement for the program is that the bulbs must be parallel. Their length must also be oriented along the z-axis with the bulb terminal at $z=0.0$. All bulbs should also be located in positive space (>0.0) in all dimensions.

The UV light intensity can be calculated for a wide variety of systems. The submerged quartz system is an example; the bulbs do not have to be symmetric in space other than being parallel to each other. A second configuration currently in use is the teflon tube system; the tubes carry the wastewater and the lamps are placed outside the tubes. The lamps and tubes are oriented parallel to one another. Schematic representations for these two system types, both of which were evaluated at Port Richmond, are presented on Figure 6-5.

Receiver Grid Analysis

A practical analysis of intensity in a submerged or teflon tube lamp battery system requires that evaluations be made at numerous receiver locations within the lamp battery. This is best accomplished with TULIP by dividing the cross-sectional space between lamps into an equal-area grid system. Examples are provided on Figure 6-6 for a submerged quartz unit

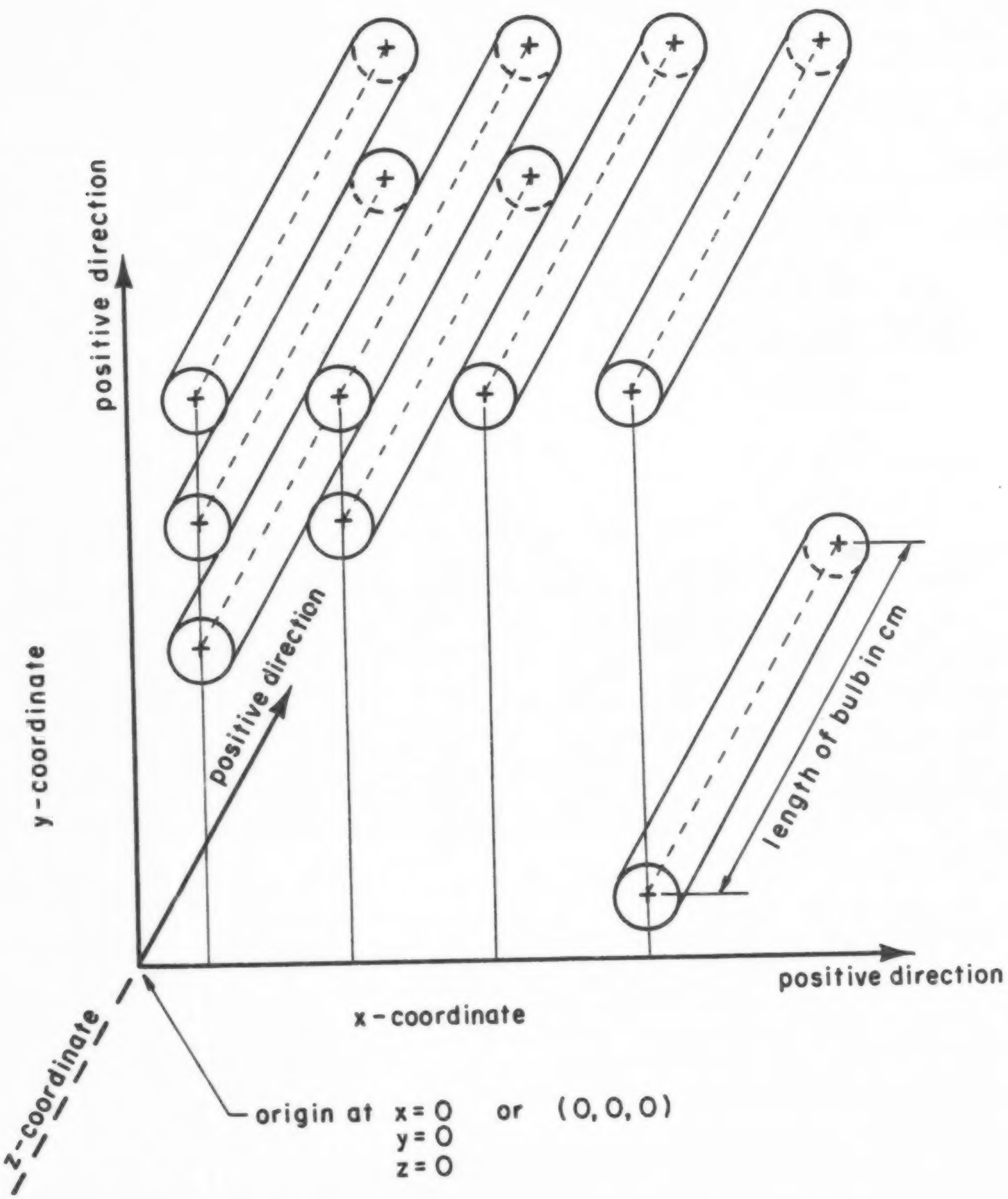
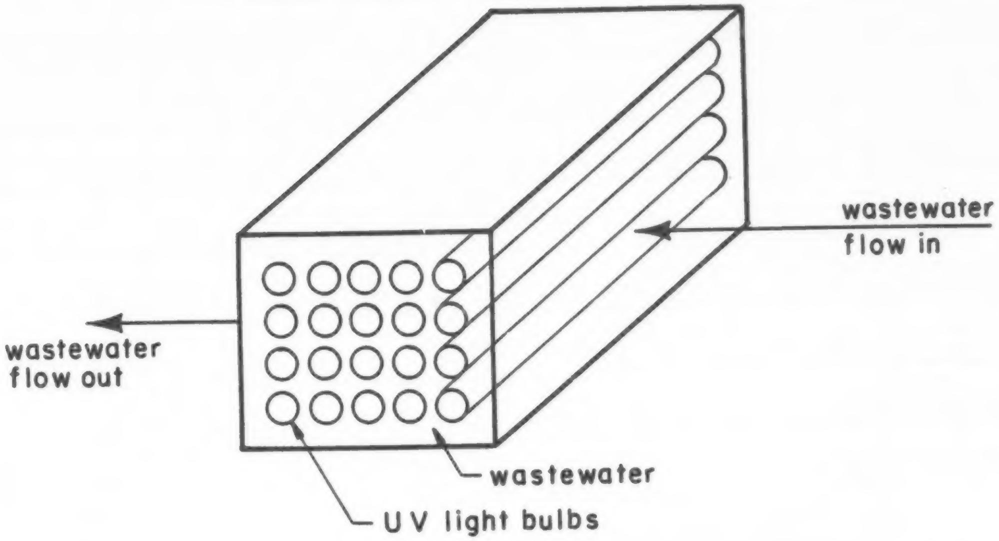
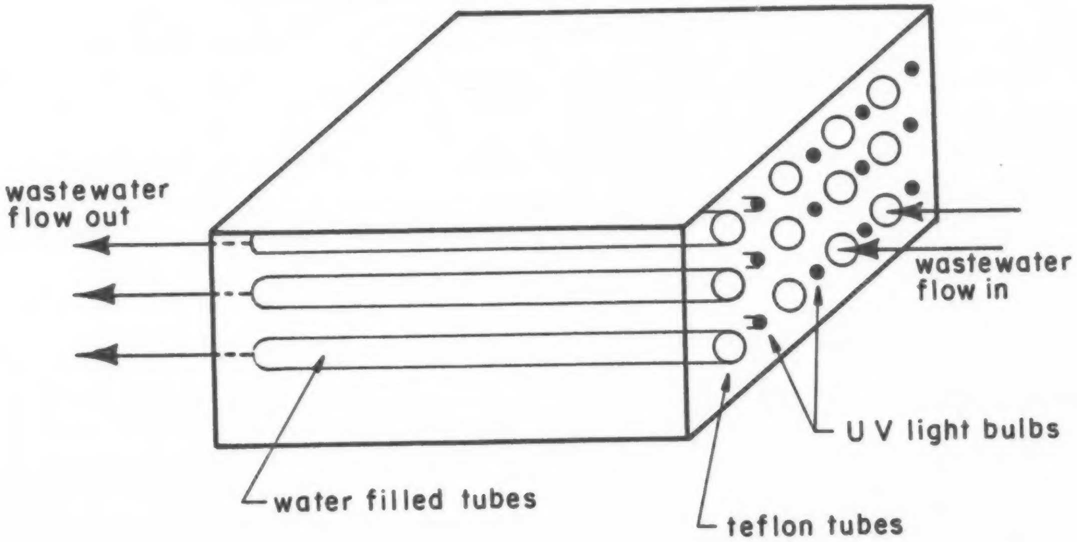

positive direction
y-coordinate
positive direction
length of bulb in cm
positive direction
x - coordinate
z-coordinate
origin at x = 0 or (0, 0, 0)
y = 0
z = 0

Figure 6-4. Three-dimensional coordinate system used in TULIP.



Schematic of a 20 bulb submerged system

wastewater flow in
wastewater flow out
wastewater
U V light bulbs



Schematic of a teflon tube system

wastewater flow out
wastewater flow in
U V light bulbs
water filled tubes
teflon tubes

Figure 6-5. Schematic diagrams of typical UV system configurations.

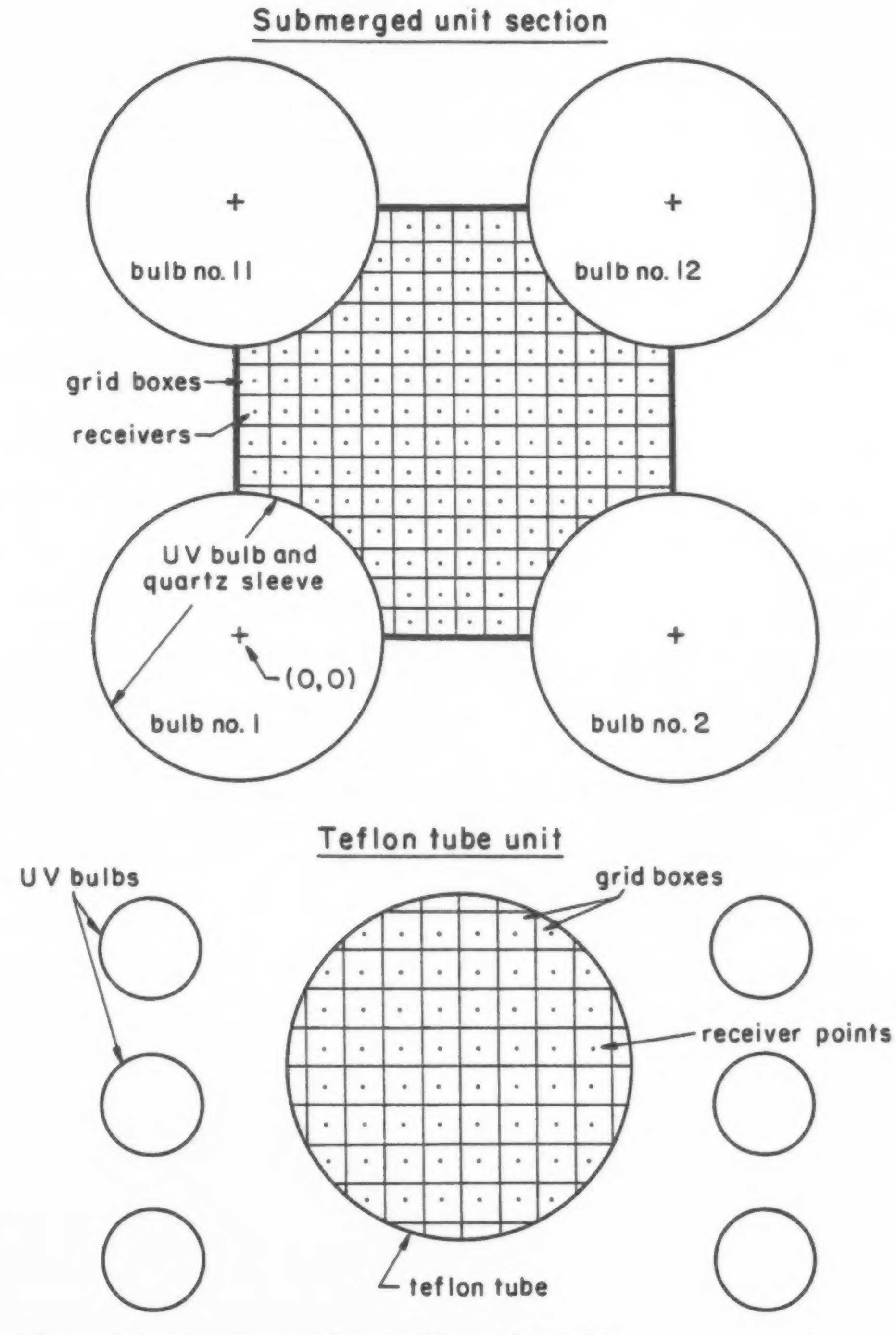

Submerged unit section
bulb no. 11
bulb no. 12
grid boxes
receivers
UV bulb and quartz sleeve
(0,0)
bulb no. 1
bulb no. 2
Teflon tube unit
UV bulbs
grid boxes
receiver points
teflon tube

Figure 6-6. Sample receiver grid configuration.

and for a teflon tube configuration, each cut in the z-plane. Receivers are then located at the center of each grid element. The program can then be used to calculate intensity at each receiver point. The average of the equal area grid elements would then be equivalent to the average intensity within the grid area. Within a system this grid can be expanded to encompass up to 300 lamps and can be moved about to evaluate boundary effects and other configurations which may affect the overall unit average intensity. By repeating these types of grid evaluations it is possible to develop an approximation of the average intensity within the entire UV battery.

PROPOSED MODEL APPLICATION

The disinfection model is applied to the Port Richmond project in Section 8 of this report. The analysis also includes use of the TULIP program to determine the average intensity in any of the three units at Port Richmond under each sampling condition.

SECTION 7

EXPERIMENTAL RESULTS

The experimental field program for the Port Richmond project covered a period of approximately 21 months. This section presents the results of the study and discusses the analysis of the data and observations made throughout the experimental phase. Empirical analyses are presented in this section; these data are again analyzed in Section 8, utilizing the mathematical modeling approach.

INTRODUCTION

The experimental phase of the project started December 1, 1981 and lasted through the latter part of September 1983. Initially, only the two quartz systems were in place. The teflon unit was not operational until August 1982. The reader is referred to Section 5 which presents a general summary (Table 5-1) of the sampling program and the operating conditions at the plant during the term of the project.

A summary log of the pilot plant operations is presented in Appendix A; this details on a daily basis the operations and sampling activities for each of the three units. Overall, there were significant problems throughout the study in maintaining operable units. Equipment malfunctions caused excessive downtime. Process related upsets at the Port Richmond plant itself caused operational problems and at times, quality control problems in the analysis of samples. The process related upsets were typically excessive foaming of the effluent and on one occasion a major oil spill into the plant.

The field data collected during the experimental phases are presented in Appendix B. Although the program was often frustrated by a number of problems that hampered or blocked the collection of acceptable data, the results which were obtained during the major periods of successful operation have provided a considerable store of information regarding system design, performance, and O&M considerations. The following discussions present these results, including a summary of the individual unit operations and a synopsis of the detailed data review which was conducted to compile an acceptable data base for subsequent analysis.

UNIT OPERATIONS

A summary of system operations for all three units is presented in Table 7-1.

TABLE 7-1. UNIT OPERATIONS SUMMARY

	December 1, 1981 to September 12, 1983		August 23, 1982 to August 25, 1983
Total Period	Unit 1	Unit 2	Unit 3
Total Number of Days[a]	595	595	329
Total Number of Operational Days	425	398	159
(% of Total)	(71.4)	(66.9)	(48.3)
Sampling Days	162	161	59
(% of Operational Days)	(38.1)	(40.5)	(37.1)
Standby Days	263	237	100
(% of Operational Days)	(61.9)	(59.5)	(62.9)
Standby Weekends/Holidays	154	136	58
(% of Standby)	(58.6)	(57.4)	(58.0)
Total Number of Down Days	170	197	170
(% of Total)	(28.6)	(33.1)	(51.7)
Equipment Downtime	129	156	138
(% of Downtime)	(75.9)	(79.1)	(81.2)
Process Downtime	41	41	32
(% of Downtime)	(24.1)	(20.9)	(18.8)

[a] Excludes period May 11 to July 11, 1983 for Units 1 and 2; and the period of May 12 to June 26, 1983 for Unit 3.

The table is divided into two sections: "operational days" and "down days." An operational day was any day an individual unit was operational, regardless of whether it was sampled or in a standby mode. A unit on standby would be operated under a low flow condition with all lamps on. This was the typical mode of operation during weekends and holidays.

The total field operations period for Units 1 and 2 (quartz) ran from December 1, 1981 to September 12, 1983. Note that the interval May 11 through July 11, 1983, is excluded from this period; thus the total number of days is 595 for both units. The field operations period for Unit 3 was August 23, 1983 to August 25, 1983. May 12, 1983 to June 26, 1983 is excluded from this period to yield a total of 329 field days for Unit 3. These excluded periods represent a suspension of the field program itself until extensions and scope changes were approved by New York City and the USEPA.

The total number of operational days for Unit 1 was 425, or 71.4 percent of the total. Of these, 162 days (38.1 percent) were utilized for sampling purposes and 263 days were considered standby. Weekends and holidays represented greater than half (58.6 percent) of the total standby days. A total of 398 operational days were accomplished for Unit 2, of which 161 (40.5 percent) were used for sampling. There were a total of 237 days when the unit was on standby, of which 136 days (57.4 percent) were weekends and holidays. Unit 3 (teflon) was operational for only 159 days, or 48.3 percent of the total. Sampling was accomplished on 59 days (37.1 percent); the unit was on standby for 100 days, of which 58 were weekends and holidays.

Downtime is divided into two categories: process related and equipment related. Process related downtime is that time when the unit was not operational because of problems at the Port Richmond plant itself or for direct program scheduling reasons, i.e., all downtime not directly associated with the UV equipment. Any non-operational downtime associated with the repair and/or maintenance of the UV systems was considered equipment downtime. Units 1 and 2 had total downtimes of 170 and 197 days, respectively. These represented 28.6 percent of the total number of field days for Unit 1 and 33.1 percent for Unit 2. Unit 3 had the highest relative downtime; this was 170 days, or 51.7 percent of the total.

System Downtime-Process Related

Process related downtime was similar for all three units. This was 41 days for Units 1 and 2, and 32 days for Unit 3. The primary cause was foaming in the plant effluent. The foaming was generally related to an industrial discharge to the plant of soap and detergent manufacturing wastes. The condition would at times be extreme; the foam itself was very thick and strong. The only recourse was to simply shut the units down until the material passed through the plant. This would take several days. In hindsight, more time should have been allowed before sampling commenced; quality control problems with the coliform analysis were later related to the samples taken during and for a period after these incidents. Six major foaming incidents were encountered causing shutdowns of up to one week (see Appendix A).

Other process related downtime periods were generally related to repair and maintenance of equipment associated with the pilot facility, but not the UV equipment. This included the two feed pumps, external piping, and flow metering equipment.

System Downtime-Equipment Related

Unit 1 experienced a total of 129 days downtime due to equipment repair or maintenance. This constituted 75.9 percent of the total downtime and 21.7 percent of the total available field time. A total equipment related downtime of 156 days was incurred by Unit 2, which comprised 79.1 percent of the unit downtime and 26.2 percent of the total field time. Unit 3 experienced 138 equipment related downtime days, which was 81.2 percent of its total downtime and 41.9 percent of its total field time.

These downtime periods were excessive, although they do include time due to problems more directly related to the fact that the facility was built as a temporary installation. A full-scale, permanent design would incorporate mechanical details and anticipate repair needs which would significantly reduce total downtime. The following discussions describe the major areas of concern regarding the repair and maintenance of the systems used at Port Richmond.

Units 1 and 2-Quartz Systems--

As had been discussed in Section 4, the only difference in the design of the two submerged quartz systems was the spacing of the lamps. Unit 1 had a spacing of 5.0 cm (surface to surface), and Unit 2 had a spacing of 1.25 cm. All other components were the same. The major equipment problems experienced with these two systems may be categorized as follows:

- mechanical wiper cable and drive cylinder failure
- quartz sleeve failure
- system leaks
- ballast failure
- monitoring/controls

Mechanical Wiper Cables and Drive Cylinders--The mechanical wipers were cable driven off a pneumatic cylinder. The stainless steel cable itself is enclosed in a teflon sheath to prevent water leakage into the cable and cylinder. Problems with the wiper cables occurred primarily during the first nine months of the program (see Appendix A) and typically on Unit 2. The cable on Unit 2 was replaced six times: late December 1981, early March 1982, mid-April 1982, mid-May 1982, late May 1982, and finally in April 1983. The cable would typically fail near its connection to the cylinder and may have been caused in part to defective cylinder blocks. These were replaced after the mid-May mishap; although the cable required repair almost immediately afterward, this was most likely due to an improper installation. The cable on this particular unit did not require any subsequent repair work until one year later.

The cable on Unit 1 required repair and/or replacement three times: mid-August 1982, and twice in March 1983. The primary problems with this system were air and water leaks from the cylinder and the teflon cable housing. The teflon cable housing would eventually develop cracks (this also happened with Unit 2) and with each cycle of the wiper, water would be sprayed from the cable sheath. This would be considerd an unacceptable electrical hazard on a full-scale system. To control leaks from the cylinders, o-ring seals were installed where the cable mounts to the cylinders.

Another problem which affected both systems was the compressor which drove the cylinders. It was undersized, and because of the constant problems with air leaks in the cables, was overworked. Nearly 30 days downtime for both units were due to problems with the compressor. The head and gaskets had to be replaced twice, and the pulley once.

Quartz Sleeves and Seals--The quartz sleeves were tightened into place with an o-ring/compression fitting. During the first few months these required tightening to prevent leaks. The greater problem occurred when a quartz sleeve actually broke within the system. This occurred several times on both units: five times on Unit 1 and four times on Unit 2. These were generally related to problems with the mechanical wiper. On Unit 1 one of the wiper glands became displaced and stressed the quartz, causing it to crack. The problems with Unit 2 occurred when the cable broke, causing the wiper to shift and subsequently causing several quartz sleeves to crack.

The ends of the quartz sleeves were not sealed in this particular design. The lamps were simply inserted into the sleeves and the end caps left exposed. When a quartz sleeve actually breaks, this arrangement can be particularly hazardous; the water pours out the end onto the floor and over neighboring lamp connections. The labor associated with replacing a damaged quartz sleeve was typically two to four hours. The task required isolating the unit and draining it completely.

Leaks--In the early months of the field program, several days were lost to resolve leaks at several points in the system. These occurred primarily at the bulkheads of the lamp battery; the influent and effluent tanks were connected at the bulkheads, with an internal gasket. Other areas which were often found to leak were the quartz to endwall seals and the teflon cable sheath. Such a high occurrence of system leaks in a full-scale system would be unacceptable.

Ballasts--The major problems incurred by the two quartz systems were due to an improper ballast installation. Ballast related problems occurred on a regular basis during the first 10 months of the field program:

- At the start of the program six ballasts required replacement after burning out.

- In April 1982, after having completed repairs on the mechanical wiper systems (cables and compressor), approximately 60 percent of the ballasts failed between the two units on startup.

- In late May and early June, overheating in the power panels began to cause shutdown and/or failure of the ballasts; approximately one dozen required replacement. To improve the cooling capacity of the high volume fans in the panels, additional vent holes were drilled into the panels.

- By August 1982, serious overheating was again causing ballast failures; small electrical fires were also occurring, particularly at the resister bars.

- On September 7, 1982 fires again occurred in both power panels; at this point both systems were shut down completely until the electrical problems could be fully resolved by the manufacturer.

The cause of the entire problem, as it was finally determined, was the improper mating of ballast and lamps. The ballasts which had been installed were designed to service two 1.6 meter (64 inch) germicidal lamps; in fact, each was wired to two 0.9 meter (36 inch) lamps. Thus, the power drawn by the lamps was considerably less than the ballasts were drawing and capable of delivering. This excess power was then discharged as heat, causing the frequent thermal failures. In September and October, both units were completely rewired such that four lamps were run off one ballast. This, in addition to the increased ventilation in the power panels, eliminated any further problems with the electrical components of the units for the remainder of the study.

Monitoring/Controls--The operation of the monitoring and control components for the two quartz systems may be summarized as follows:

- The wiper cycling timers were effective and operational through the entire term of the study.

- The elapsed time clocks for monitoring total operational time for the lamps were found to be useful and were operational throughout the study.

- A temperature probe was supplied with the units to monitor lamp temperature. It was comprised of a meter and thin rod-like thermister which was wrapped with aluminum foil onto the surface of a selected lamp. This particular element of the study was not successful. The instrument itself did not operate consistently; additionally, it was very difficult to obtain representative readings from lamp to lamp and along the length of a single lamp. Lamp temperature is important to the proper operation of a UV system and future efforts in full-scale application should address an adequate design which will measure actual skin temperature at an appropriate point along the lamp.

- A variac had been supplied to allow varying the voltage to each system. This study element was to address intensity reduction by voltage reduction as an energy conservation measure (in lieu of turning lamps on or off). Problems with the oversized ballasts (discussed in the preceding section) in effect caused only minor decreases in intensity with decreasing voltage; the oversized ballasts were keeping the actual power to the lamps relatively constant. The variac was not used for the study.

- Three intensity probes were installed with each unit; these were placed at the top of the lamp battery to monitor the output from a lamp in each of the three banks. A gland on the mechanical wiper would wipe the probe window with each stroke. All three probes were read by a single meter which would give an output relative to the intensity in clean water (or other known calibration conditions). The probes and meters were found to be unreliable. The units required frequent repair and calibration checks and the output was generally inconsistent. It was never clear whether the probe output was being affected by poor cleaning of the probe window or other factors not directly associated with the output of the lamps. Use of the intensity monitors was discontinued early in the study.

- The LED pilot indicators were installed to monitor the operation of each lamp in a unit. These were not wholly effective for this particular study; it was not consistently clear whether the lamp was inoperable or the LED itself had failed. In the latter half of the study use of the LEDs were abandoned and the lamps themselves were inspected on a daily basis. The LEDs are generally very reliable; their unreliability during this study may have been due more to poor wiring and excessive heat in the power panels.

Unit 3-Teflon System--

As stated earlier, Unit 3 suffered the greatest downtime due to equipment problems. Much of this was due to poor fabrication at the factory and delivery of a unit which did not meet its original design specifications. The major problem areas were:

- The system delivered to the site was not weatherproof, a specified requirement. Additionally, the wiring was poor. Both problems were resolved by the manufacturer in the months of September and October 1982; the unit was rewired, and a shelter was constructed to house the unit next to the existing UV pilot facility.

- The hydraulic design of the system was inadequate; the influent gate structures and effluent weirs for each of the unit compartment required modification. The unit still could not handle the design hydraulic loading. This in turn put limitations on the scope of the experimental program.

Ballasts--The ballasts were installed in this system atop each lamp rack in an aluminum housing. Fans were provided to cool the lamp/teflon tube compartment, which included the ballast housing (see Section 4). Although not provided with this particular system, these fans could be thermostatically controlled to maintain optimum temperatures for proper lamp operation. During cold temperature months the ballast heat would be retained, while during the warm months the heat would be vented from the system.

A number of problems were encountered with the ballasts overheating and shutting down. One modification necessary was to drill vent holes into the aluminum housing; this was found to be effective in minimizing the number of times the ballast would trip off because of overheating.

Monitoring/Controls--The operation of the monitoring and control systems provided with the teflon system may be summarized as follows:

- Fiber optic strands were used to monitor the operation of the lamps. One drawback in the design, however, was that only one of two lamps would be monitored per ballast. This presumed that if one lamp were out the other would also be inoperative. This was not the case, as it was observed that one lamp could be on and the other simply flickering at low intensity. Thus, the lamp monitoring system was considered to be unreliable; unfortunately, there was no effective way of determining the actual number of lamps in operation at any given time.

- As with the quartz systems, a temperature monitor was provided with the system which proved to be unreliable and was eventually discarded.

- Relative intensity probes and monitors were provided with the system. The detectors in this case were inserted into a top teflon tube in each of the four compartments. The first intensity monitoring system failed within the first week of startup and was replaced by the manufacturer. This new system was found to be erratic in its output and was eventually shutdown. The manufacturer made no further attempt to get the system operational.

System Maintenance

The level of downtime associated directly with equipment breakdown and repair was needlessly excessive. Based on the experiences of this project and other large-scale installations these problems should in large part be avoided through careful and considered design. Specific tasks, however, will remain a part of the system's normal O&M needs and will incur downtime. They are also tasks that can, under most circumstances, be scheduled so as to minimize any impact on plant operations:

- lamp battery cleaning
- parts replacement
- lamp UV output determination

Lamp Battery Cleaning--

The two quartz systems had mechanical wipers to maintain the outer surface of the quartz sheaths. These were used throughout the term of the project. Although direct evaluations of the effectiveness of the wipers were not successful, it is felt that they were a useful component and certainly were effective in keeping the surfaces clear of any small debris. The fact that the program was of a research nature demanded that any bias between the two quartz systems due to wiper proficiency be eliminated. Thus, the two units were always cleaned chemically on any sampling day.

Please note that an attempt had been made to directly evaluate the wipers, but a freak occurrence forced a rejection of all bacteriological data obtained during this period. In mid-November 1982 the plant suffered a midgefly infestation; this was eventually brought under control by spraying insecticide and by the onset of cold weather. During December and January, several sampling runs were made with the two quartz units; one unit would be operated with the wiper on while the second would have no wiper in operation. The data obtained from these periods were poor, in the sense that the disinfection performance of either system was greatly reduced and there was little discernable difference between the two units.

It was finally discovered in late January 1983 that the midgeflies had clustered inside the quartz sleeves; large amounts of detritus were found, effectively blocking penetration. Since there was no way to legitimately quantify the effects of this material, the bacteriological data collected during this period was deemed unacceptable. Other program requirements did not allow for a subsequent evaluation of wiper effectiveness.

Quartz Units—Regardless of a particular system's accessory cleaning equipment, it is likely that periodic chemical and/or detergent cleaning will be required to maintain the outer quartz surface. This is particularly the case where the wastewater is relatively dirty (secondary effluent), has a relatively high grease or oil content, or has a high hardness content. A major cause of fouling the quartz surfaces has been found to be inorganic magnesium and calcium carbonates. The inorganic deposition is also the easiest to control; simple acidification of the reactor water will generally dissolve the material and restore the surface. In the case of organic fouling (usually from a high grease content) it is necessary to use a detergent or some combination of cleaning agents. This is typically determined by trial and error for a particular situation.

At Port Richmond, a combination of acid and an industrial detergent was used. The unit was isolated by diverting flow to the second unit; acid was then added to adjust the pH to approximately three. The detergent was then added to the influent tank. The wiper stroke rate would usually be increased to assist the cleaning operation. This procedure was found to be very effective and typically required no more than one hour of a single operator's time.

Certainly, an operational concern regarding this aspect of system maintenance is determining the frequency and/or need to chemically clean. An in-place intensity monitor would be effective. The monitors provided with all three units at Port Richmond were found to be ineffective, however, and operationally unreliable. There are added concerns for this type of fixed placed detector; the window for the probe must be maintained in some fashion, the probe sees only the surfaces in the immediate vicinity, and the probe cannot directly account for the absorbance characteristics of the wastewater itself. A portable radiometer was found to be more effective at Port Richmond, when used in conjunction with the UV absorbance measurements taken on each sampling.

As described earlier in Section 5, the IL 570 intensity measurements were taken by placing the detector at selected (and reproducible) positions along the influent and exit planes of the lamp battery. For effective monitoring, these readings must be taken frequently, and only the current history should be considered, i.e., the monitoring for surface fouling should not cover periods of such length that the aging of the lamps will have a significant effect on the readings. Figure 7-1 presents an example taken from Port Richmond of the relationship of the IL 570 readings versus the absorbance coefficient of the wastewater. These readings were all made after the unit was chemically cleaned and all within two months. This relationship is important, not from the absolute intensity readings as a function of absorbance, since these will change with lamp age, but from the relative change as a function of absorbance. In this particular example, the intensity is shown relative to the intensity at an absorbance coefficient of 0.2 cm^{-1}. Thus, by knowing the relative effects of the wastewater absorbance, the operator can make reasonable judgements from the radiometer readings as to the condition of the quartz surfaces.

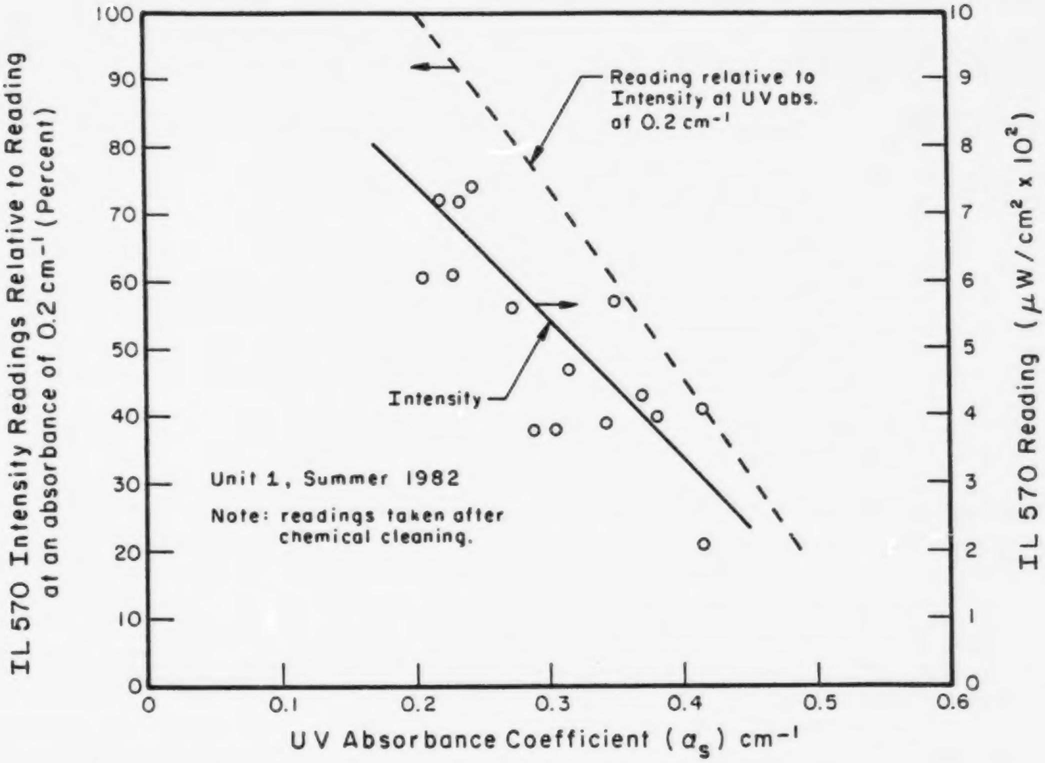


Figure 7-1. Example of radiometer intensity readings as a function of UV absorbance.

An evaluation of cleaning frequency requirements was not made on a long term basis for the Port Richmond study, as had been discussed earlier. It should be understood that this will vary from site to site, depending on wastewater quality and the system design. Figure 7-2 is presented as an example of chemical cleaning effects as measured by a radiometer for Unit 1 at Port Richmond. These readings were taken during the summer 1982; recall that the units were chemically cleaned each day the units were to be sampled. The data shown on Figure 7-2 are from those days when measurements were taken immediately before and after the cleaning cycle.

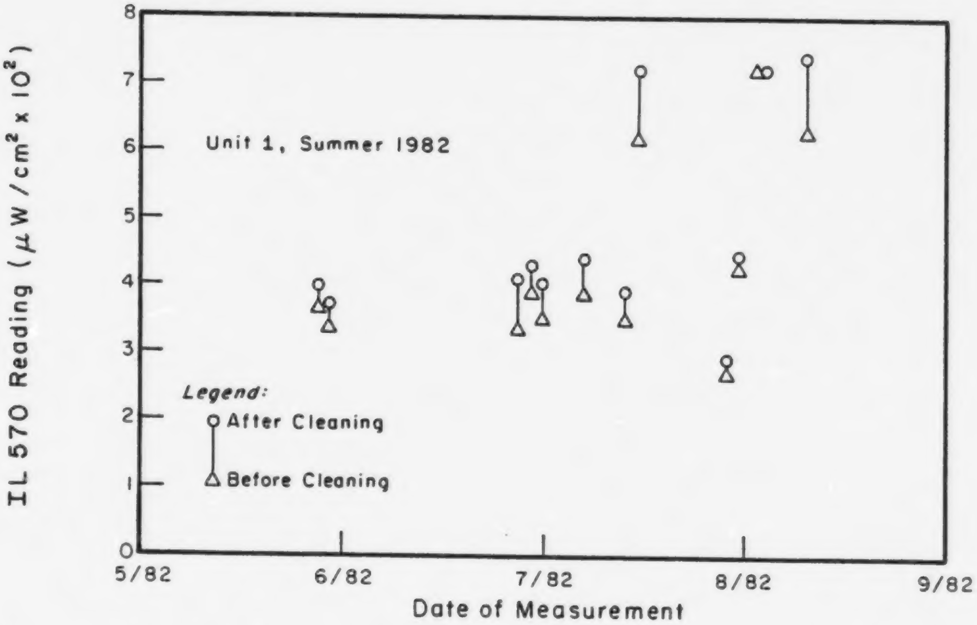


Figure 7-2. Example of chemical cleaning effects, based on radiometer measurements.

Typically, the cleaning resulted in improvements of 10 to 20 percent in intensity; there also were days when the data showed that cleaning was not necessary (late July, early August). Note that the wiper was in operation throughout this period.

The outer quartz surface maintenance was not the only cleaning task required for proper operation of the quartz systems. The inside quartz surfaces and the lamp surfaces were also found to accumulate a dirt film, and required periodic cleaning. The procedures are outlined in Section 5. This task was done three times during the study and once at the end of the program. A later subsection discusses the impact of these conditions (inner and outer surface fouling) on the overall output of the lamps.

These particular systems had open quartz sleeve ends; the lamps would simply be slipped into the quartz, with the endcaps left exposed. Sealing these ends may minimize the fouling of the inside surfaces. In all, it is estimated that the full cleaning procedure, which required removing each of the lamps, took approximately four man-days for the two 100 lamp units.

System Cleaning - Teflon (Unit 3)--The teflon system did not have any accessory cleaning equipment. Theoretically, it was to rely on the hydrophobic properties of the teflon to discourage fouling of the teflon surface. This was not the case. The surfaces were found to foul and to require cleaning. Due to the operational history of the unit, no direct evaluation of the degree of fouling could be obtained from the study.

As discussed earlier, the teflon system was put on line in late August 1982. The unit was operated for approximately three weeks before being shutdown for repairs. Wastewater was allowed to sit in the teflon tubes for a period of two months, before it was again started in November 1982. This is certainly not the proper way to hold a system in standby; the unit should have been fully drained and kept in a dry dustfree condition. (This also applies to the quartz systems.) The tubes had developed a slime coating which was found to be very difficult to remove. A considerable effort was expended in December and January to determine an effective in-place cleaning method. This included an acidic and detergent cleaning with recirculation pumps, which proved ineffective for the teflon tube. It became apparent that a scrubbing action was required, in addition to simply contacting the walls with a cleaning agent. Snaking a flexible rod (with a cloth ball at the end) down the tube was effective but cumbersome, particularly with the poor access to the lower tubes.

In February, the 6.0 cm I.D. teflon tubes in the first compartment were replaced with new 8.9 cm I.D. tubes. Since the manufacturer indicated that all new systems would have these larger diameter tubes, all subsequent testing was conducted only on the first compartment. Samples were taken from Unit 3 in March through May 1983, and in the latter half of July without cleaning the teflon tubes. At this point, the oil spill occurred at Port Richmond, which effectively fouled the tubes with an oily film.

A new cleaning system was evaluated at this time by the manufacturer in an attempt to restore the teflon surfaces. It was comprised of a flexible high pressure water hose (with pump) with a circular spray nozzle at the end. The hose was snaked down the individual tubes spraying water at a pressure between 300 and 400 psi (the unit is capable of operating at pressures up to 800 psi). This technique was found to be very effective when a detergent solution was educted into the high pressure water stream. The tubes were observed to be very clean; the operation itself can be accomplished within one hour for eight, three meter tubes.

As had been described earlier, the teflon unit had vent fans to circulate air within the lamp/tube compartment and to pull in air for cooling and temperature control. At Port Richmond this also caused dust to be brought into the system, eventually causing a layer of grime to accumulate on the surfaces of the teflon tubes and the lamps. It was necessary to manually clean each tube and lamp with a detergent solution and to wipe each dry. This was done only once; the fans were subsequently shut off. The cleaning task was especially difficult for the particular system design at Port Richmond because of the very poor access to the lower parts of the unit. In any newer design there should be filters on the air fans and vents to minimize the dust problem, and design changes should be made to incorporate better access to the lamps and tubes.

Parts Replacement/Repair--

The major replacement items for the UV systems would be:

- ballasts
- lamps
- quartz enclosures or teflon tubes

It is not possible, from the experience of this field study to judge precisely the frequency of replacement or the labor requirement for each task at a full-scale facility. The following suggestions can be offered, however:

1. An appropriate inventory of these items should be maintained to minimize any lost time due to simply not having the parts on hand.

2. The ballasts should be independent of the UV unit and maximum ventilation provided to keep them cool. Stacking the ballasts in the power panel made it difficult at times to remove individual ballasts.

3. Actual lamp replacement must be made as simple a task as possible since it is the one which will most frequently occur. This can be accomplished in a matter of minutes as long as the lamps are accessible and easily disconnected. This was found to be the case with the quartz systems but not the teflon unit.

4. Replacement of failed quartz or teflon tubes was a task requiring isolation of the unit and complete drainage. Replacement of the quartz sleeve was relatively easy; replacement of a teflon tube, other than the one at the top was very difficult and time consuming.

5. Other components which will require attention are the glands on the mechanical wiper, the cable and wiper drive assembly, the power panel fans, and the seals at all system connection points (particularly quartz to bulkhead, teflon to bulkhead). Failure or operational problems with these particular components will cause disruptions in performance and possible damage to the unit. Routine inspection should be made an element of the plant's operating schedule to guard against these incidents.

6. The accessary components to the UV system would include all monitoring equipment (intensity, temperature, elapsed time recorders, etc.) and automatic control systems. Although important to operations, their failure should not preclude the continued operation of the unit in manual mode. The experience at Port Richmond suggests that for the great majority of system applications, it is best to keep the system as simple as possible regarding instrumentation and automatic controls.

The greater attention should be paid to keeping the key components in good order, and minimizing operator time in maintaining non-essential components.

Lamp Monitoring--

An important monitoring task for the efficient operation of a UV system is the direct measure of lamp output at 254 nm. The procedure used at Port Richmond was described in Section 5; the results are presented in subsequent discussions. The estimated lamp life suggested by the lamp manufacturers is approximately 7500 hours, and is dependent upon the operating conditions of the UV system. It is suggested that the lamps be measured for output at least once each six months. Monitoring the lamps in this fashion should allow the operator to make maximum use of the individual lamps, and to assure that there is an appropriate mix of lamps relative to a desired average output. This task can be conducted concurrently with the full cleanup procedure suggested earlier. The lamp output monitoring task, based on the Port Richmond experience, can be accomplished by two operators over a period of two eight-hour days for approximately 100 lamps.

DATA SELECTION

The analytical data collected during the experimental phase are provided in Appendix B. These data reflect a critical review designed to compile an edited base with only those data of acceptable quality. These edits were primarily addressed to the bacteriological measurements. The review and reasons for deletion of selected data sets are summarized in the following discussions.

There was a total of 513 samplings conducted within the term of the field program. A sampling is defined as drawing an influent sample and corresponding effluent samples from each of the operating units. Thus, a single sampling may incorporate effluents from one, two or three units, depending on the program design. Unit 1 was sampled 389 times; Unit 2 had 361 samplings, while Unit 3 was sampled 110 times.

Certain sets of the coliform data were excluded from the final data base for the following process related reasons:

1. The entire period between mid-November 1982 and early February 1983 was deleted for all three units. The reasons for this were the excessive dirtiness of the teflon unit, and the midgefly problem described earlier for the quartz units. This resulted in the rejection of 54, 58, and 47 samplings for Units 1, 2, and 3, respectively.

2. As had been discussed earlier, foaming at times caused severe problems at the plant, generally causing the UV units to be shutdown until the material appeared to have passed through the system. At this time the sampling would again commence; in hindsight this would at times commence too early. Residual material appeared to have a toxicity effect in the coliform analyses. This was evidenced by increasing recoveries with increasing dilutions or no recoveries at all in certain cases. This was also the problem with a number of samples taken after the oil spill in July 1983. In all, the number of samplings rejected due to the the foaming and/or oil spill problems was 23 and 24 for Units 1 and 2, respectively.

Thus, after deleting sampling sets for the above reasons, the acceptable samplings were reduced to 312 for Unit 1, 279 for Unit 2, and 63 for Unit 3. These data were then reviewed for consistency and quality. Any further deletions were made for the following reasons:

1. If either the influent or effluent coliform analysis failed for a sampling, the sampling results would be of no use for subsequent data analyses. These samplings were rejected. Typically, this was due to missed dilutions; although four dilutions were set, the variability often found with the Port Richmond effluent would at times cause the density to jump outside the expected range.

2. Rejections were also due to any quality control problems. These were primarily related to poor media for either the fecal or total coliform

enumerations. Although the plates would be checked for quality before use, there were occasions when highly inconsistent results were obtained, with the cause generally traceable to the media. This was due either to the preparation or to a bad batch of the raw material.

3. A number of rejections were from a period when an interfering growth was evident on the plates after incubation. This would overgrow the coliform colonies and make enumeration impossible. The cause was not determined; the problem occured during a defined period of the summer of 1982, and did not reoccur.

The quality control problems were generally in the first six months of the study. Nearly all data collected in 1983 was acceptable on a quality control basis (i.e., confirmation and replicates). In all, the final review of the coliform data resulted in the acceptance of 231 total and 236 fecal coliform samplings for Unit 1 (74 and 76 percent acceptance levels, respectively). Unit 2 has a final base of 207 total and 205 fecal coliform data (74 and 73 percent acceptance levels respectively), and Unit 3 had a 78 percent acceptance level, with 47 total and fecal coliform data.

Water quality analyses were conducted on only the influent to the UV systems. Of the 513 samplings, 478 were with a secondary effluent and 35 were primary effluent. Greater than 95 percent acceptance was accomplished for the primary effluent water quality parameters; this was also the case for each secondary effluent water quality parameter, except TOC (60 percent) and COD (85 percent). Instrument problems with the Beckman TOC analyzer in the early months of the study caused a rejection of a large number of TOC analysis results from that period.

WATER QUALITY

A primary design element for the program at Port Richmond was to evaluate the effectiveness of UV with a wastewater which was highly variable in quality. This was successful; the secondary effluent at Port Richmond ranged from a polished, nitrified effluent to a low grade secondary effluent. Additionally, it was possible on a limited basis to test the systems with primary effluent. The reader is reminded that the total record of water quality data is provided in Appendix B.

Secondary Effluent

Table 7-2 is a summary of the total edited record of water quality data for the secondary effluent. These are averages of grab samples taken as the influent to the UV systems. The table also displays the number of samples represented by the mean, and the coefficient of variation for each of the chemical water quality parameters. The coefficient of variation in this case is defined as the standard deviation expressed as a percentage of the mean and is a measure of the spread or variability observed for a particular parameter.

Tables 7-3 through 7-7 provide summaries of the monthly averages for all parameters measured during experimental period: Table 7-3 presents the coliform data; Table 7-4 summarizes the COD and TOC results; the UV absorbance coefficient results are presented in Table 7-5; Table 7-6 displays the turbidity, suspended solids, temperature, and pH data; and, finally, the nitrogen series data are presented in Table 7-7. The information shown for each parameter are the number of samples, the monthly mean, and the standard deviation.

The total coliforms had a geometric mean of 1.02×10^6 col/100 ml, with the fecal coliforms averaging approximately 3.61×10^5 col/100 ml. Chronological records of the monthly means are displayed on Figure 7-3 for both total and fecal coliforms. Linear regression analysis of the influent and effluent total and fecal coliforms yielded the following correlations for the secondary effluent data:

Influent:

$$\text{Log Influent Total Coliforms} = 0.882(\text{Log Influent Fecal Coliforms}) + 1.09 \qquad (7\text{-}1)$$

TABLE 7-2. SUMMARY OF PORT RICHMOND SECONDARY EFFLUENT WATER QUALITY DATA (December 1981 through August 1983)

Parameter	Number of Samples	Mean	Coefficient of Variation[a] (%)
Total Coliform (col/100 ml)	396	1.016×10^6 (GM)[b]	-
Fecal Coliform (col/100 ml)	398	3.61×10^5 (GM)[b]	-
Chemical Oxygen Demand (mg/l)			
Total	350	44.5	40.7
Filtered	346	32.8	37.5
Total Organic Carbon (mg/l)			
Total	242	12.8	42.9
Filtered	237	11.7	44.4
UV Absorbance Coefficient (cm^{-1} at 253.7 nm)			
Direct - Total	476	0.466	36.6
Filtered	477	0.404	30.6
Spherical - Total	476	0.372	30.1
Filtered	477	0.358	27.7
Suspended Solids (mg/l)	443	14.3	87.4
Turbidity (NTU)	418	4.0	97.5
pH (S.U.)	437	7.3	-
Total Kjehldahl Nitrogen (mg N/l)			
Total	105	6.9	88.4
Filtered	104	5.3	69.8
Ammonia (mg N/l)	100	5.3	73.5
Nitrite (mg N/l)	64	0.416	128.0
Nitrate (mg N/l)	93	3.31	103.0

[a] Standard Deviation expressed as percent of mean.
[b] Geometric Mean

TABLE 7-3. MONTHLY AVERAGE OF PORT RICHMOND SECONDARY EFFLUENT COLIFORM DATA[a]

	Log Total Coliform			Log Fecal Coliform		
Month	n	$\bar{x}$	S.D.	n	$\bar{x}$	S.D.
December 1981	31	6.386	0.749	17	5.151	0.346
January 1982	21	6.095	0.230	22	5.598	0.284
February	12	6.380	0.400	12	5.843	0.379
March	6	6.068	0.262	18	5.629	0.253
April	-	-	-	0	-	-
May	12	5.820	0.399	13	5.382	0.424
June	29	5.752	0.280	29	5.398	0.294
July	19	5.970	0.205	19	5.672	0.161
August	23	5.991	0.409	28	5.796	0.466
September	9	5.932	0.134	9	5.514	0.199
October	16	5.827	0.229	15	5.513	0.435
November	18	6.244	0.424	18	5.771	0.432
December	26	6.148	0.339	26	5.622	0.375
January 1983	39	6.354	0.417	39	5.704	0.401
February	12	6.073	0.215	12	5.449	0.355
March	24	5.820	0.437	24	5.449	0.428
April	41	5.679	0.146	41	5.359	0.206
May	6	6.290	0.069	6	5.810	0.141
June	12	6.448	0.676	12	6.229	0.797
July	9	6.353	0.553	9	6.033	0.548
August	31	5.404	0.297	29	5.114	0.315

[a] All grab samples taken of the influent to the UV systems between 9 a.m. and 4 p.m.
Note: n = number of samples; $\bar{x}$ = mean; S.D. = standard deviation.

TABLE 7-4. MONTHLY AVERAGE OF PORT RICHMOND SECONDARY EFFLUENT COD AND TOC[a]

	Chemical Oxygen Demand - COD (mg/l)						Total Organic Carbon - TOC (mg/l)					
	Total			Filtered			Total			Filtered		
Month	n	$\bar{x}$	S.D.	n	$\bar{x}$	S.D.	n	$\bar{x}$	S.D.	n	$\bar{x}$	S.D.
December 81	31	50.9	17.0	31	38.3	14.9	28	16.8	5.6	28	14.1	3.5
January 82	15	51.6	23.2	15	42.7	21.0	15	21.2	9.1	15	20.0	7.5
February	3	44.0	8.0	3	37.3	9.2	3	18.3	3.8	3	20.5	1.8
March	27	42.8	12.7	27	30.3	8.5	27	9.1	4.5	26	6.9	2.7
April	4	57.5	3.7	4	37.0	7.4	4	15.9	1.7	4	13.0	2.2
May	19	50.3	22.8	17	40.4	12.7	22	15.5	3.2	22	13.2	4.5
June	28	34.6	5.4	27	28.5	3.7	30	9.9	2.1	30	8.5	1.6
July	20	31.3	7.9	20	29.8	6.8	20	9.4	2.1	20	9.8	2.4
August	30	33.3	10.0	30	27.6	7.1	30	10.1	4.4	30	9.4	3.5
September	7	35.6	14.1	6	25.7	9.6	7	10.3	3.5	7	11.1	2.8
October	-	-	-	-	-	-	-	-	-	-	-	-
November	20	57.1	27.8	20	40.4	17.8	11	13.5	4.4	12	17.1	6.6
December	18	60.7	24.4	18	32.9	14.2	-	-	-	-	-	-
January 83	33	53.9	18.5	33	38.6	15.0	-	-	-	-	-	-
February	12	54.1	11.0	12	27.3	5.7	-	-	-	-	-	-
March	24	43.9	10.7	24	31.1	8.3	-	-	-	-	-	-
April	31	34.8	10.1	31	24.0	5.0	18	12.8	3.1	15	11.0	1.9
May	2	59.0	4.2	2	39.0	7.1	1	16.0	-	1	13.0	-
June	4	30.5	5.2	4	28.8	5.0	4	9.5	2.4	3	16.0	6.6
July	10	50.8	15.0	10	37.9	10.0	10	15.4	3.2	10	11.4	3.5
August	12	30.5	5.3	12	26.3	4.6	12	13.6	4.3	11	12.2	5.6

[a] All grab samples taken of the influent to the UV system between 9 a.m. and 4 p.m.

Note: n = number of analyses; $\bar{x}$ = mean; S.D. = standard deviation.

TABLE 7-5. MONTHLY AVERAGE UV ABSORBANCE COEFFICIENT OF PORT RICHMOND SECONDARY EFFLUENT[a]

	Direct (cm^{-1})[b]						Spherical (cm^{-1})[b]					
	Total			Filtered			Total			Filtered		
Month	n	$\bar{x}$	S.D.	n	$\bar{x}$	S.D.	n	$\bar{x}$	S.D.	n	$\bar{x}$	S.D.
December 81	34	0.403	0.114	34	0.310	0.051	34	0.300	0.050	34	0.287	0.047
January 82	22	0.585	0.277	22	0.465	0.209	22	0.446	0.223	22	0.417	0.175
February	19	0.629	0.238	19	0.543	0.204	19	0.462	0.145	19	0.431	0.109
March	27	0.479	0.096	27	0.434	0.092	27	0.404	0.077	27	0.363	0.070
April	4	0.655	0.085	4	0.475	0.020	4	0.456	0.051	4	0.382	0.008
May	22	0.541	0.122	23	0.438	0.078	22	0.376	0.127	23	0.337	0.103
June	30	0.436	0.105	30	0.369	0.057	30	0.336	0.051	30	0.337	0.059
July	16	0.335	0.078	16	0.329	0.080	16	0.294	0.071	16	0.294	0.075
August	30	0.358	0.092	30	0.348	0.081	30	0.324	0.079	30	0.328	0.077
September	8	0.318	0.069	8	0.318	0.077	8	0.295	0.098	8	0.299	0.105
October	17	0.363	0.037	17	0.321	0.041	17	0.306	0.045	17	0.314	0.043
November	26	0.434	0.106	26	0.416	0.087	26	0.348	0.074	26	0.367	0.078
December	27	0.426	0.124	27	0.410	0.119	27	0.383	0.105	27	0.388	0.113
January 83	40	0.559	0.118	40	0.479	0.140	40	0.435	0.105	40	0.417	0.103
February	12	0.505	0.041	12	0.386	0.048	12	0.366	0.043	12	0.343	0.053
March	24	0.464	0.072	24	0.389	0.063	24	0.382	0.053	24	0.356	0.052
April	42	0.343	0.046	42	0.327	0.037	42	0.303	0.038	42	0.294	0.032
May	6	0.613	0.039	6	0.500	0.063	6	0.508	0.040	6	0.466	0.066
June	12	0.408	0.077	12	0.409	0.082	12	0.367	0.071	12	0.377	0.074
July	26	0.716	0.273	26	0.515	0.182	26	0.456	0.166	26	0.407	0.145
August	32	0.441	0.076	32	0.418	0.080	32	0.395	0.084	32	0.389	0.081

[a] All grab samples taken of the influent to the UV systems between 9 a.m. and 4 p.m.

[b] Coefficients are base e.

Note: n = number of analyses; $\bar{x}$ = mean; S.D. = standard deviation.

TABLE 7-6. MONTHLY AVERAGES OF PORT RICHMOND SECONDARY EFFLUENT TURBIDITY, SUSPENDED SOLIDS, TEMPERATURE, AND pH[a]

Month	Turbidity (NTU)			Suspended Solids (mg/1)			Temperature (°C)			pH (S.U.)
	n	x	S.D.	n	x	S.D.	n	x	S.D.	x
December 81	34	6.0	5.0	34	22.1	17.6	-	-	-	6.8
January 82	18	3.7	1.1	22	13.7	5.9	7	11.6	0.5	7.0
February	12	7.4	8.7	12	25.3	14.3	8	11.1	1.2	6.8
March	27	5.6	1.3	27	23.6	8.3	10	12.1	0.4	7.1
April	3	12.4	4.0	3	58.3	11.0	2	14.5	-	7.0
May	15	6.1	6.3	16	29.6	19.5	8	16.9	1.2	7.4
June	29	0.8	0.5	29	9.3	4.4	6	19.9	0.5	7.1
July	15	1.0	0.5	20	3.9	1.5	8	22.1	1.0	7.2
August	29	0.7	0.3	29	5.7	5.6	10	23.1	0.4	7.4
September	8	0.5	0.2	9	5.2	2.6	2	22.8	0.4	7.9
October	14	1.6	1.8	17	7.7	2.2	10	20.7	2.2	7.4
November	24	1.7	2.0	24	14.1	9.7	12	18.6	1.5	7.2
December	27	3.2	2.5	27	12.1	4.4	8	17.4	1.2	7.2
January 83	39	5.9	3.9	38	19.0	17.6	17	13.6	1.8	7.6
February	12	8.2	4.6	12	24.7	5.8	6	12.0	0.8	7.6
March	24	6.7	3.6	24	14.4	6.7	12	12.0	0.8	7.7
April	34	4.2	1.9	42	12.2	8.9	8	12.6	1.1	7.6
May	2	7.4	1.6	6	15.5	7.8	2	13.0	4.2	7.6
June	12	1.6	0.3	12	5.1	2.8	3	20.8	0.3	7.0
July	9	4.4	1.3	9	13.4	2.9	10	22.9	0.6	7.1
August	31	3.8	1.0	31	6.3	2.7	14	22.9	0.5	7.3

[a] All grab samples taken of the influent to the UV systems between 9 a.m. and 4 p.m.

Note: n = number of analyses; $\bar{x}$ = mean; S.D. = standard deviation.

TABLE 7-7. MONTHLY AVERAGES OF PORT RICHMOND SECONDARY EFFLUENT NITROGEN SERIES[a]

Month	Total Kjeldahl Nitrogen - TKN (mg/1)						Ammonia-N (mg/1)			Nitrite-N (mg/1)			Nitrate-N (mg/1)		
	Total			Filtered											
	n	$\bar{x}$	S.D.	n	$\bar{x}$	S.D.	n	$\bar{x}$	S.D.	n	$\bar{x}$	S.D.	n	$\bar{x}$	S.D.
December 81	7	5.3	1.4	7	4.2	0.8	7	2.3	0.7	7	0.22	0.17	7	3.0	2.6
January 82	13	8.5	4.3	13	6.0	2.1	13	5.0	3.1	4	0.09	0.04	10	2.2	2.8
February	2	11.4	2.4	2	8.0	2.4	2	9.1	0.1	2	0.05	0.01	2	0.08	0.4
March	3	12.3	0.6	3	10.3	0.6	3	9.8	0.6	1	0.50	-	3	0.08	0.04
April	3	9.1	2.4	3	1.0	0.8	3	0.5	0.7	3	0.64	0.89	3	2.8	4.73
May	6	10.5	2.1	6	8.3	0.9	6	7.4	1.1	3	0.06	0.01	3	0.16	0.04
June	9	4.2	2.2	9	5.5	4.4	6	4.0	2.6	3	0.72	0.08	9	5.5	2.2
July	12	1.7	0.8	12	2.5	0.4	12	2.1	0.9	11	0.35	0.22	12	3.4	2.2
August	6	0.9	0.1	6	0.9	0.1	6	0.6	0.4	4	0.38	0.26	6	7.4	0.91
September	5	0.7	0.4	5	1.0	0.7	5	0.3	0.1	5	0.30	0.20	5	4.7	2.3
October	7	4.8	3.1	7	7.1	3.2	7	5.8	2.9	7	1.0	1.1	7	5.5	1.2
November	6	3.6	4.5	6	3.5	4.5	4	4.0	4.5	2	1.2	-	6	9.4	4.8
December	10	8.9	3.2	9	8.0	1.6	9	8.6	2.2	9	0.38	0.51	5	0.3	0.15
January 83	11	15.2	11.2	11	10.5	3.0	11	10.0	3.5	3	0.11	0.09	10	0.28	0.16
February	2	9.5	2.1	3	5.5	3.6	3	9.4	3.0	-	-	-	3	0.31	0.17
March	3	9.7	2.2	2	9.0	0.3	2	8.5	1.3	-	-	-	3	0.23	0.04

[a] Grab samples taken of influent to the UV systems between 9 a.m. and 4 p.m.

Note: n = number of samples; $\bar{x}$ = mean; S.D. = standard deviation.

Effluent:

Unit 1;
Log Effluent Total Coliforms = 0.996(Log Effluent Fecal Coliforms) + 0.493 (7-2)

Unit 2;
Log Effluent Total Coliforms = 0.977(Log Effluent Fecal Coliforms) + 0.531 (7-3)

The coliform densities are measured by the membrane filtration technique, with the units colonies/100 ml. The values of r^2 (square of the correlation coefficient, r) for the three expressions are 0.77, 0.92, and 0.91, respectively. The ratio of total to fecal coliforms for the unexposed secondary effluent is approximately four. The correlations for the exposed effluent from either of the two UV units was essentially the same. The ratio of total to fecal coliforms was approximately three. Within the precision experienced for the coliform analyses, these data suggest that the total and fecal coliforms have the same sensitivity to UV.

The averages for the chemical water quality parameters (Table 7-2) are consistent with a secondary effluent quality; the COD averaged 44.5 mg/l and the suspended solids averaged 14.3 mg/l. There was a high degree of variation, however, as represented by the coefficients of variation (Table 7-2). Figure 7-3 displays chronologically the monthly averages for turbidity, suspended solids, and COD. Other chronologic plots are presented on Figure 7-4; these are for pH, temperature, TOC, and the nitrogen series. The high variability experienced at Port Richmond is generally attributable to the seasonal operating conditions at the plant. During the colder months the effluent was poorer in quality as shown by the elevated levels of COD, suspended solids and turbidity. During the warmer months, higher removals were achieved; this was generally accompanied by the onset of nitrification. As shown on Figure 7-4 a high degree of nitrification was being achieved during the summer and fall of 1982.

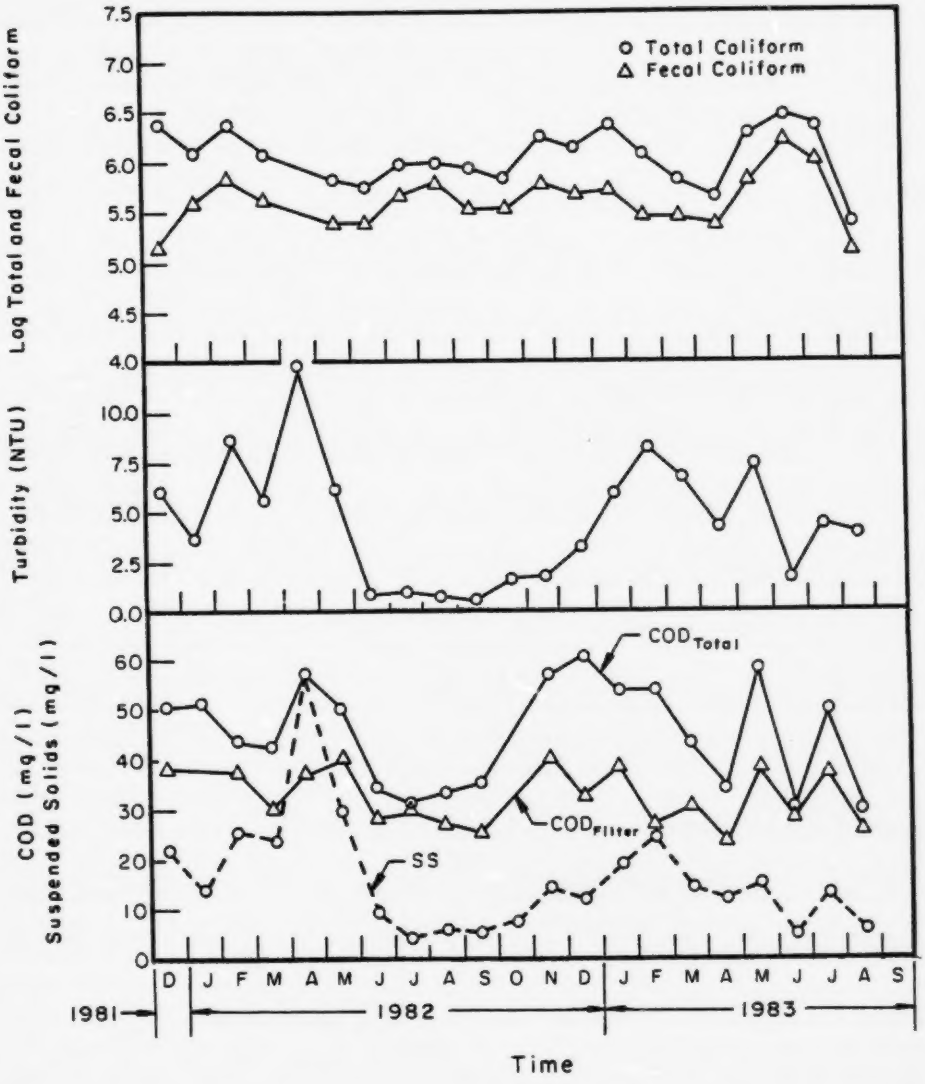


Figure 7-3. Chronological record of monthly averages: UV influent total and fecal coliforms, turbidity, suspended solids and chemical oxygen demand.

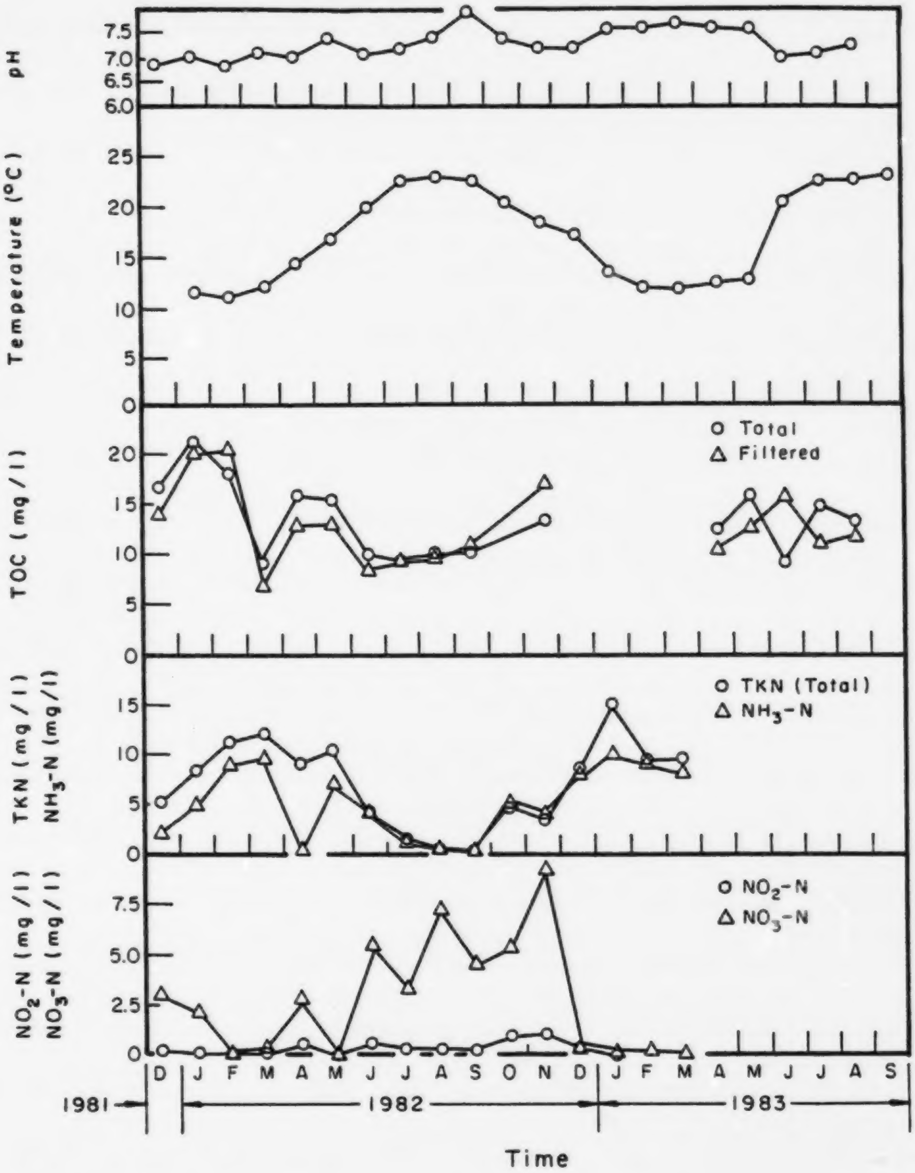


Figure 7-4. Chronological records of monthly averages: UV influent pH, temperature, total organic carbon, total kjeldahl nitrogen, ammonia nitrogen, nitrite nitrogen, and nitrate nitrogen.

The critical parameter in the evaluation and design of UV systems is the absorbance of the wastewater at 253.7 nm. Within the context of this report the absorbance characteristic of the water is described by the absorbance coefficient, α, which is base e and has the units cm^{-1}. It is a natural log transformation of the base 10 spectrophotometric absorbance units.

The absorbance coefficient was measured by two methods, as had been described in Section 5. The first method was simply a spectrophotometric measurement of the absorbance of a direct beam of light (at a wavelength of 253.7 nm) which is passed through a 1 cm quartz cell. By this method, light which does not penetrate the liquid and reach the detector is assumed to have been absorbed by the sample. Within the context of this report, this measurement is referred to as the "direct" UV absorbance coefficient, or α_D.

The second method is a modification of the direct beam method and incorporates an integrating sphere about the quartz cell. This sphere measures the light which is scattered from the sample and corrects the direct beam measurement for this scattering effect. The method, in effect, is a more accurate measure of the "true" absorbance of the liquid. This measurement is referred to as the "spherical" absorbance coefficient, α_S. The spherical absorbance coefficient is felt to be the more appropriate measure of water quality for UV design purposes since it reflects the actual loss of energy to the liquid. Energy which is scattered is likely to be still available for disinfection.

Both absorbance coefficients were measured on filtered and unfiltered (total) aliquots of each influent sample. The overall and monthly averages for the secondary effluent are presented in Tables 7-2 and 7-5, respectively. The monthly averages are chronologically displayed on Figure 7-5. As shown, the results of the direct absorbance measurement, both total and filtered, are higher than those measured by the spherical method, indicating that the routine direct measurement method overestimates the loss of energy in the liquid. There is a fraction of this energy which is

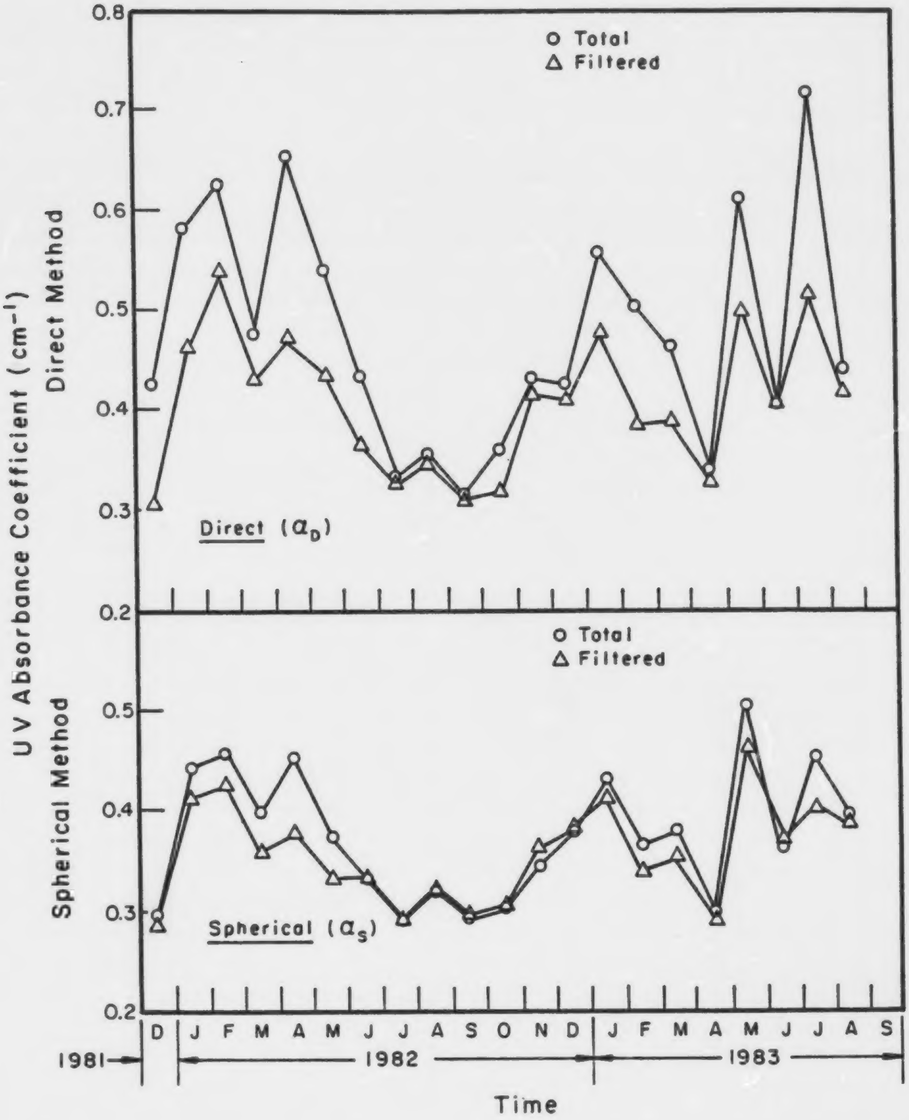


Figure 7-5. Chronological records of monthly average UV absorbance coefficient (base e, 253.7 nm).

simply being scattered. This can be further explained by converting the absorbance coefficients to percent of energy absorbed (100% - %T):

	Average cm^{-1}	Percent Absorbed
Direct α_D,total	0.466	37.2
Direct α_D,filtered	0.404	33.3
Spherical α_S,total	0.372	31.9
Spherical α_S,filtered	0.358	30.2

The percent absorbance values are also shown chronologically on Figure 7-6. Based on the overall averages, the direct method on the total sample is approximately 17 percent higher than the absorbance measured by the spherical method. The direct method for the filtered sample is still higher than the spherical total, indicating there is still some scattering even after filtration. There is little difference between the spherical measurement of either the total or filtered sample. This suggests minimal absorbance of the energy by the particulate matter found in the secondary effluent. It also supports the utility of the spherical measurement in UV design and performance analysis when attempting to define the true absorbance characteristics of the liquid to be treated.

Regression Analyses of Secondary Effluent (Influent to UV Units) Water Quality Parameters--

A series of linear regression analyses were conducted to determine the correlations which exist between the parameters and to determine if there existed a way of predicting coliform densities and absorbance characteristics from the more routine water quality analyses.

The correlations of coliform density with the various water quality parameters were generally poor. Those of significance were:

$$\text{Log Total Coliform} = 0.0146\ (\text{total COD}) + 5.93 \ldots\ldots r = 0.493 \qquad (7\text{-}4)$$

$$\text{Log Total Coliform} = 0.0167\ (\text{total COD}) - 0.0184\ (\text{turbidity}) + 5.39 \ldots\ldots r = 0.502 \qquad (7\text{-}5)$$

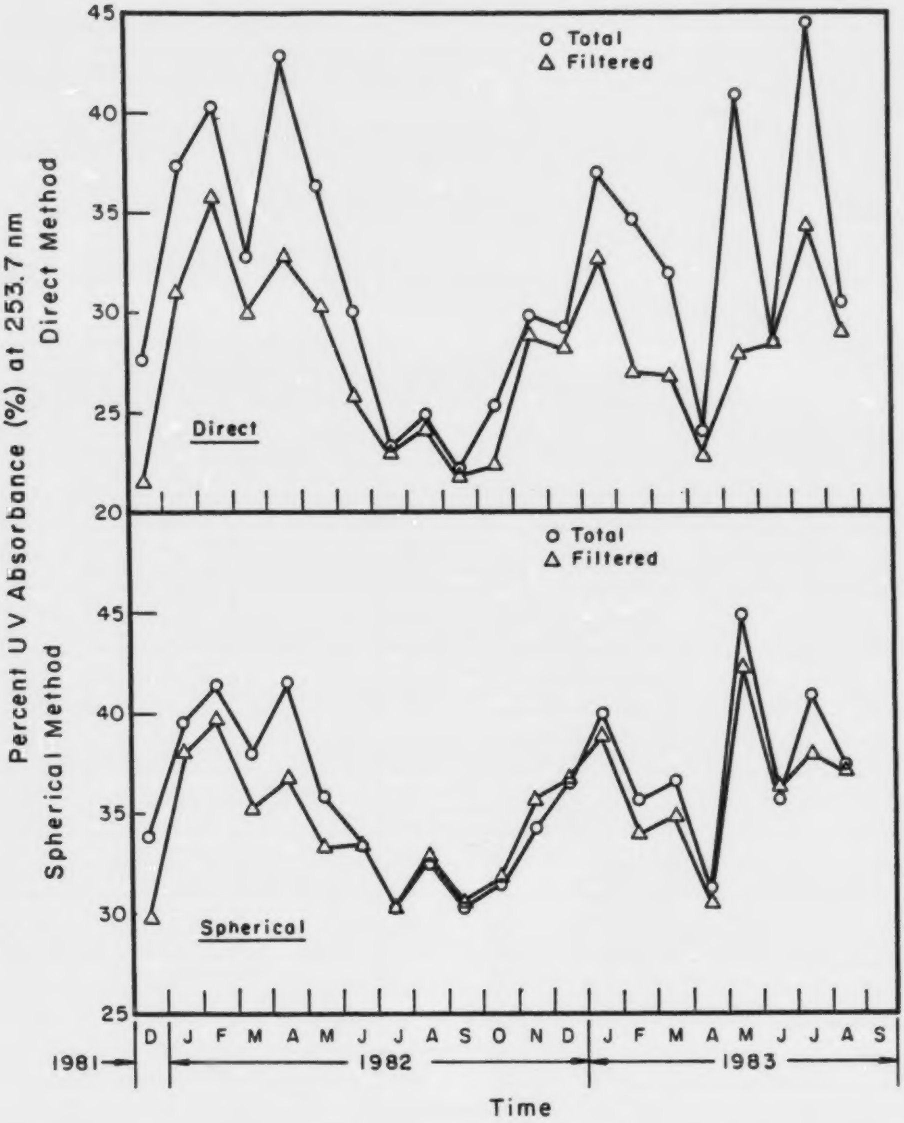


Figure 7-6. Chronological records of monthly average UV percent absorbance.

As indicated, the total COD was found to correlate weakly with the total coliform. Turbidity and suspended solids did not individually correlate well with coliform, nor did either parameter improve the correlation in a multiple regression analysis with the COD. The other parameters measured as part of the program, including UV absorbance, TOC, and the nitrogens, were found to be of little value in approximating either total or fecal coliform densities.

COD was found to be the better indicator of the absorbance coefficient, although again the regressions were weak:

$$\alpha_S \text{ (total)} = 0.0025 \text{ (total COD)} + 0.255 \ldots r = 0.416 \qquad (7\text{-}6)$$

Adding turbidity (or suspended solids) to the analysis did little to improve the regression:

$$\alpha_S \text{ (total)} = 0.0016 \text{ (total COD)} + 0.0058 \text{ (turbidity)} + 0.267 \ldots r = 0.422 \qquad (7\text{-}7)$$

Similar results were obtained when the absorbance coefficient was converted to percent absorbance.

Primary Effluent

A summary of the water quality data for the primary effluent samplings is presented in Table 7-8. Total coliforms averaged (geometric mean) 3.17×10^7; the fecal coliform averaged 1.26×10^7. A linear regression analysis yielded the following expressions:

TABLE 7-8. SUMMARY OF PORT RICHMOND PRIMARY EFFLUENT WATER QUALITY DATA (AUGUST TO SEPTEMBER 1983)

Parameter	Number of Samples	Mean	Coefficient of Variation[a] (%)
Total Coliform (col/100 ml)	35	3.17×10^7 (GM)[b]	-
Fecal Coliform (col/100 ml)	35	1.25×10^7 (GM)[b]	-
Chemical Oxygen Demand (mg/l)			
Total	15	134	21.6
Filtered	14	42	20.6
Total Organic Carbon (mg/l)			
Total	15	31.9	25.6
Filtered	13	20.1	31.8
UV Absorbance Coefficient (cm^{-1} at 253.7 nm)			
Direct - total	35	0.865	29.9
filtered	35	0.747	25.5
Spherical - total	35	0.593	23.9
filtered	35	0.533	24.3
Suspended Solids (mg/l)	35	80.9	46.7
Turbidity (mg/l)	34	25.7	44.3

[a] Standard deviation expressed as percent of mean.
[b] Geometric Mean

Influent:

$$\text{Log Total Coliform} = 0.688\ (\text{Log Fecal Coliform}) + 2.64$$
$$r = 0.732 \qquad (7\text{-}8)$$

Effluent - Unit 1:

$$\text{Log Total Coliform} = 0.857\ (\text{Log Fecal Coliform}) + 1.21$$
$$r = 0.945 \qquad (7\text{-}9)$$

Effluent - Unit 2:

$$\text{Log Total Coliform} = 0.844\ (\text{Log Fecal Coliform}) + 1.18$$
$$r = 0.925 \qquad (7\text{-}10)$$

The expressions for the two effluents are essentially the same. The ratio of total to fecal coliforms for the exposed samples ranged between 5 to 1 and 10 to 1 at the lower density levels (less than 10^4). This is similar to the ratio for the influent at levels of 10^6 to 10^7.

As with the secondary effluent data, a series of linear and multiple linear regression analyses were conducted for the primary effluent data, although the data base was significantly smaller. These were directed primarily to relating water quality with the measured UV absorbance coefficients. In this case the COD was not effective alone in describing the absorbance characteristics of the wastewater:

$$\alpha_S \text{ (total)} = 0.0018 \text{ (COD-total)} + 0.342 \ldots r = 0.256 \qquad (7\text{-}11)$$

The COD and turbidity, however, were found to be improved predictors of the UV absorbance:

$$\alpha_S \text{ (total)} = 0.0044 \text{ (COD-total)} + 0.0026 \text{ (turbidity)} - 0.047$$
$$r = 0.623 \qquad (7\text{-}12)$$

Suspended solids in lieu of the turbidity was not effective for this regression.

Continuous UV Absorbance Monitor

A continuously recording monitor of UV absorbance (General Atomic Inc.) was operated for a short time in the summer of 1983. The readings were taken at times corresponding to sampling for UV absorbance measurements. The monitor readings, in absorbance units in a 1.5 cm cell (au/1.5 cm) are displayed on Figure 7-7 against corresponding measurements of the UV absorbance coefficient, α_S (total). Certainly, more time and data would be required to more clearly demonstrate the monitor's performance. However, the limited data do show that the monitor is effective and may be very useful in monitoring water quality for direct control of UV system operations.

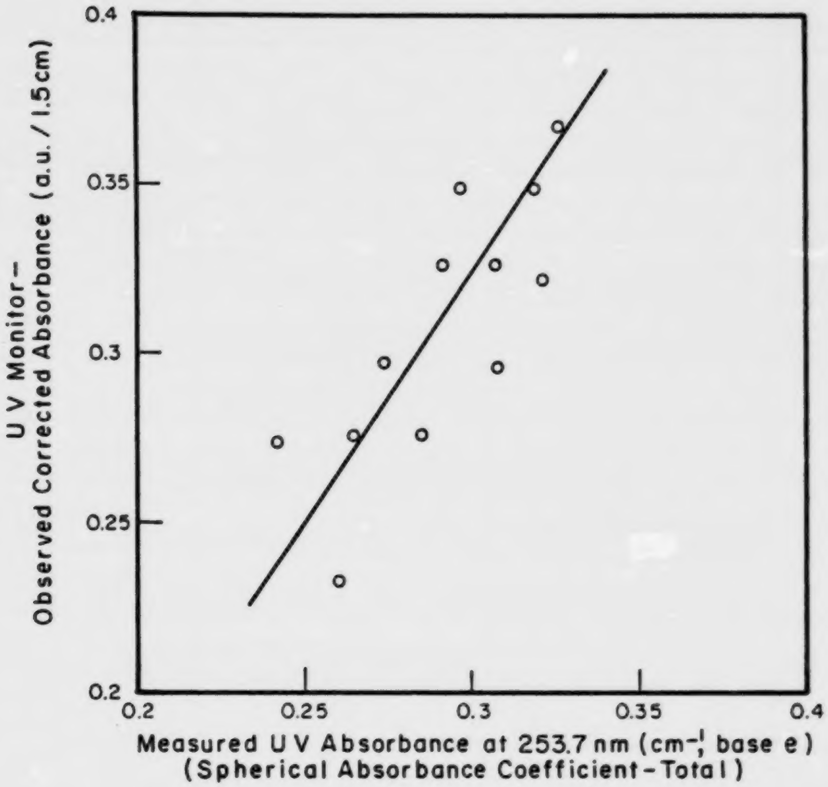


Figure 7-7. Continuous UV absorbance monitor reading compared to UV absorbance coefficient measurements.

HYDRAULIC CHARACTERIZATION

Direct measurements were performed on the quartz systems (Units 1 and 2) to define their hydraulic characteristics. The tests were directed to estimating the dispersion coefficient and determining the head losses through the lamp batteries. The procedures for these tests were given in Section 5. The relative importance of the hydraulic design of a UV system was also discussed in Section 6, which presented the framework by which the dispersion characteristics are incorporated into the proposed mathematical model for UV disinfection.

Recall that the critical elements of an efficient hydraulic design for UV systems are to approach plug flow and to have turbulent conditions as the water moves through the system. The following discussions present the results of tests which were conducted at Port Richmond in an attempt to define these elements. Note that these tests were conducted only on the quartz units; direct testing was not conducted on the teflon unit.

Before presenting the results, it is appropriate to reiterate some of the discussion from Section 4. The first element of any effective design will be an acceptable approach condition. Extreme variations in the approach velocity across the inlet cross-section of the lamp battery will encourage short-circuiting and/or ineffective use of the system. Before startup of the field program both quartz units were tested to evaluate the distribution of flow across the face of the lamp battery. This was accomplished by an instantaneous injection of dye upstream of the influent tank. The dye was then observed as it passed through the unit.

Significant gradients were found, particularly on Unit 1. This was due (including Unit 2 to a lesser degree) to the position of the inlet pipe to the influent tank and to the relatively small size of the influent tank. Sufficient time and volume were not available to dissipate and equalize the velocity before entering the lamp battery. Overflow wiers and stilling walls were subsequently installed in each tank to correct this problem. Further tests and observations indicated a good flow distribution across the plane of the lamp battery, with no evidence of short circuiting.

Dispersion Characteristics of the Quartz Systems

As had been discussed in Section 5, a tracer die-away technique was used to develop a time-distribution curve for the quartz units. In this method (schematically presented on Figure 5-3), a continuous injection of a concentrated salt solution was made at a fixed position approximately 5 cm in front of the first vertical row of lamps. A conductivity probe was then moved about the exit cross-sectional plane of the unit, approximately 5 cm from the last vertical row of lamps. These readings would locate and define the salt plume as it exited the lamp battery.

Figure 7-8 is an example of the conductivity profile constructed at the exit of Unit 2. The flow rate during this particular run was 1360 lpm.

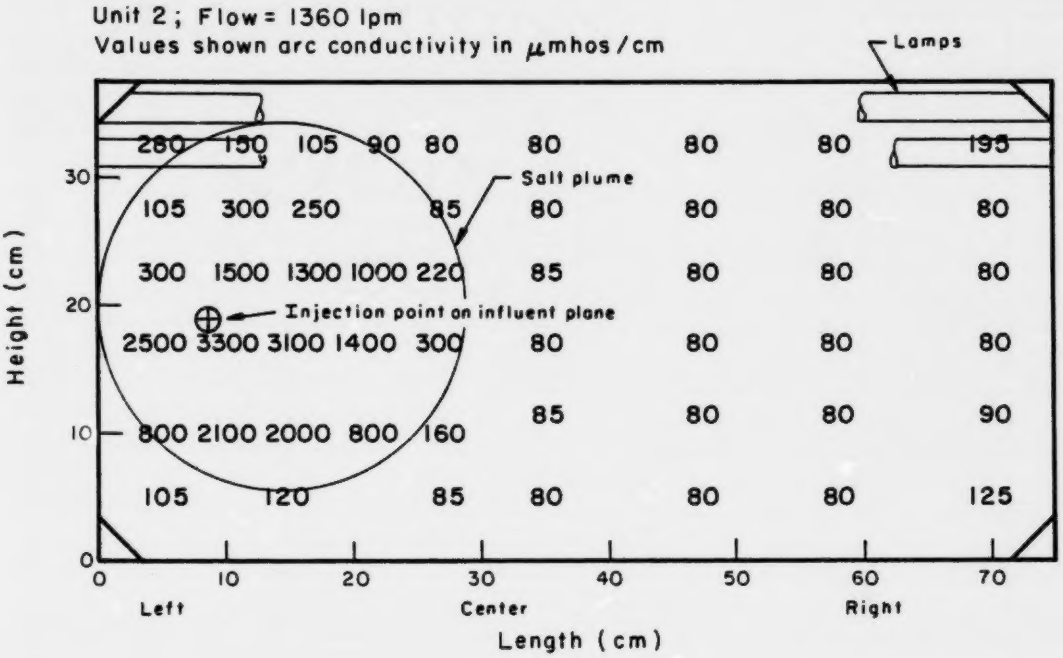

Unit 2; Flow = 1360 lpm
Values shown arc conductivity in μmhos/cm
Lamps
Salt plume
Injection point on influent plane
280 150 105 90 80 80 80 80 195
105 300 250 85 80 80 80 80
300 1500 1300 1000 220 85 80 80 80
2500 3300 3100 1400 300 80 80 80 80
800 2100 2000 800 160 85 80 80 90
105 120 85 80 80 80 125
Height (cm)
0
10
20
30
0
10
20
30
40
50
60
70
Left
Center
Right
Length (cm)

Figure 7-8. Example of conductivity profile across exit plane of lamp battery (lloking toward lamps).

The position of the injection point is also shown; in this case it was on the left side of the lamp battery, looking into the unit from the effluent end. Several points should be made at this time regarding the procedure and the application to Port Richmond:

1. The background conductivity at Port Richmond was very high due to significant saltwater intrusion into the plant's collection system. This prevented use of the wastewater as the carrier for the salt injection. New York City potable water was used instead, drawn from a nearby fire hydrant. This water had a very constant background conductivity of approximately 80 μmhos/cm. Having to use the hydrant as the source of water also limited the maximum flow rate which could be tested to less than 1500 lpm.

2. Care should be taken in setting the concentration levels of the saltwater to be injected. If the concentraion is too high there is the danger of creating high density differences with the background water. At lower flow rates the salt injection will actually sink, negating the utility of the test.

3. The salt solution should be injected at a velocity only slightly higher than the background velocity. This will minimize undesirable mixing conditions from occuring at the point of entry of the salt into the wastestream.

Returning to Figure 7-8, the conductivity measurements are shown to approximate the location and boundary of the plume as it exits the lamp battery. The conductivity probe would then be positioned in the vicinity of the maximum salt concentration in the salt plume. At this point, the continuous salt solution injection would be shut-off. This shut-off would be automatically recorded as an event on the high speed recording oscillograph. The conductivity meter/oscillograph would then record conductivity as the salt would wash out and the conductivity return to background. Using a salt concentration to conductivity calibration and the known recording chart speed, it was then possible to construct the die-away curve of salt concentration (gm/l) versus time (seconds).

Figure 7-9 presents an example (upper display) of the resulting tracer die-away curve. The derivative of this curve is then taken by plotting the slopes (dc/dt) of tangents drawn at points along the curve. The dc/dt data are then plotted against time, resulting in the time-distribution, or dispersion curve shown on the lower display of Figure 7-9.

The primary use of these data was to estimate a dispersion coefficient, E, representative of each of the quartz units. This was done by a series of trial and error solutions of the following expression, using E as the variable to fit the observed data:

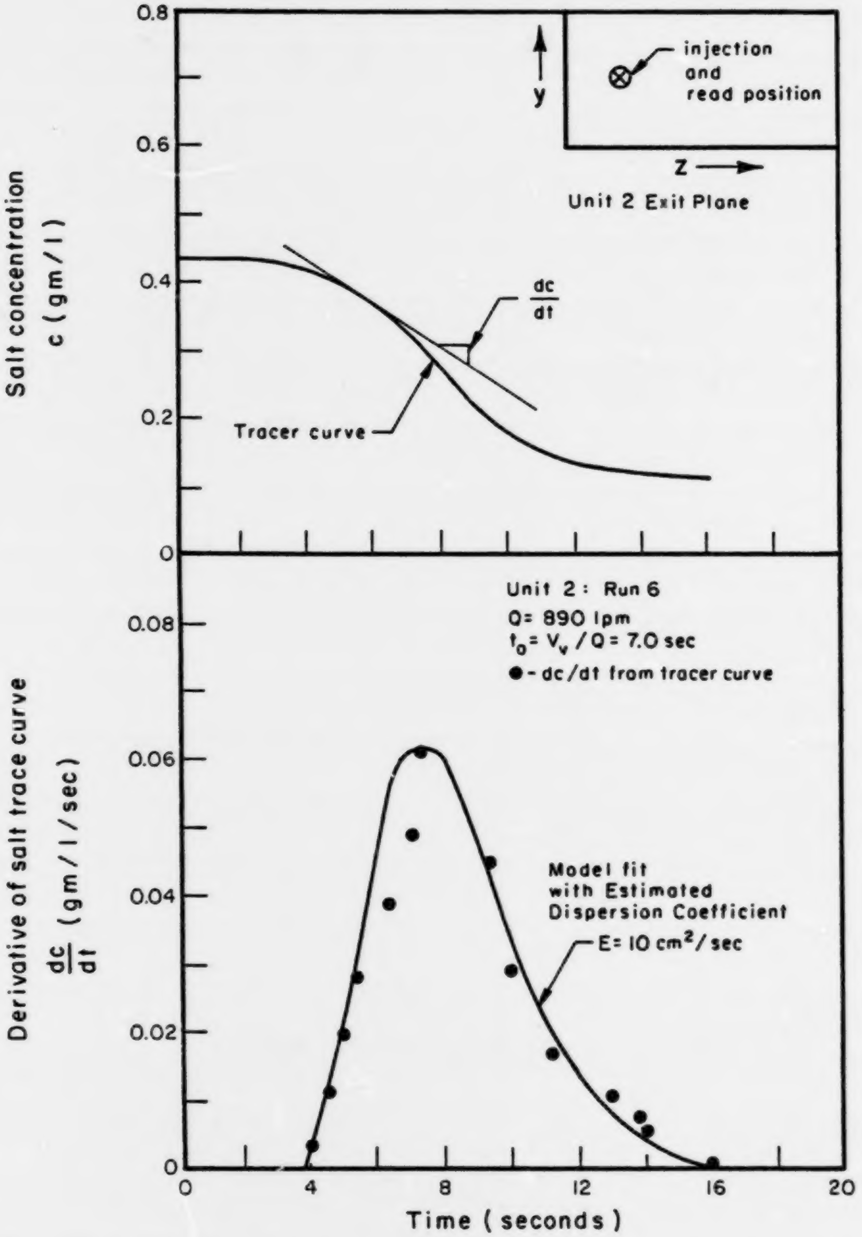


Figure 7-9. Example of tracer analysis on Unit 2 and estimate of the dispersion coefficient.

$$\frac{dc}{dt} = \frac{W}{2A(\pi Et)^{1/2}} \exp\left[\frac{-(x - ut)^2}{4Et}\right] \qquad (7\text{-}13)$$

where:

dc/dt = observed change in concentration with time (gm/1/sec)

W = rate of mass input (gm/sec)

A = cross-sectional area of the salt stream at x (cm^2)

x = distance from injection to observation point (cm)

u = velocity (cm/sec)

t = time (sec)

E = dispersion coefficient (cm^2/sec)

The velocity is computed as the distance traveled per theoretical detention time:

$$u = x/(V_v/Q) \qquad (7\text{-}14)$$

If the peak is presumed to occur at the theoretical retention time, a constant c' can be defined at $t = t_o$:

$$\frac{W}{2A(\pi E)^{1/2}} = c'(t_o)^{1/2} \qquad (7\text{-}15)$$

using Figure 7-9 as an example, t_o, is 7 seconds; at t_o, the value of dc/dt is 0.06 gm/1/sec. Since the exponential term goes to 1 at $t = t_o$, then:

$0.06 = c' \ (7)^{1/2}$; and $c' = 0.0227$

This c' term can be substituted into Equation (7-13):

$$dc/dt = c'(t)^{1/2} \exp[-(x-ut)^2/ 4Et] \qquad (7\text{-}16)$$

With fixed values of x and u for a given system and flow, different values of E can be evaluated until a best fit of the dc/dt versus t data is obtained. As shown on Figure 7-9, an E = 10 cm^2/sec was found to be a good approximation.

Figures 7-10 and 7-11 present a number of dispersion curves and solutions for E for Units 1 and 2, respectively. A summary of the dispersion coefficients estimated from all tracer analyses on both units is presented on Figure 7-12. No significant influence on the dispersion coefficient was apparent due to flow variation or from the position in the unit. There was an inherent variability in the estimates of E from each test: the range was 0.5 to 2.0 cm^2/sec for Unit 1; for Unit 2 the estimate ranged from 5 to 30 cm^2/sec. An obvious observation is the marked difference between the two units; overall values of 1.5 cm^2/sec and 15 cm^2/sec were assigned to Units 1 and 2, respectively, a factor of ten difference. Upon closer inspection, however, this should be expected. Unit 2 is compact, with a relatively short time of travel and high velocity compared to the longer and slower Unit 1. Unit 2 would be more susceptible to dispersive mixing and should be represented by a higher dispersion coefficient.

The examples shown on Figures 7-10 and 7-11 typically show a tailing of the observed data which is not precisely reflected in most cases by the dispersion model equation. Although more complex solutions can be formulated to accurately reflect these tailing effects, this was considered unnecessary since the critical portion of the time-distribution curve for disinfection purposes is the first half (i.e., before the occurrence of the theoretical or average detention time). The solutions were therefore directed to fitting as best possible this first portion of the curve.

It should also be noted that the time of occurrence of the peak dc/dt for either unit was generally very close to the theoretical detention time. This indicates that there was little evidence of short-circuiting and that there was a good distribution of flow across the entire unit with full use of the lamp battery's effective volume.

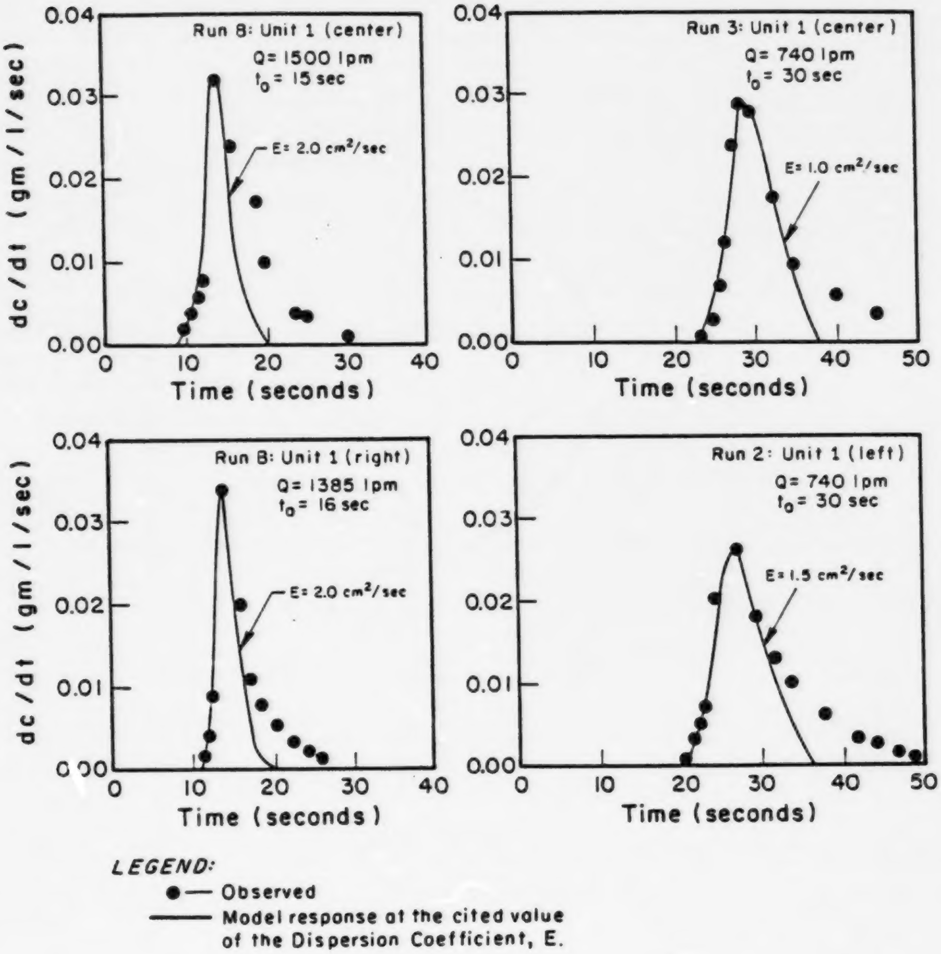


Figure 7-10. Dispersion curves and estimates of E for Unit 1.

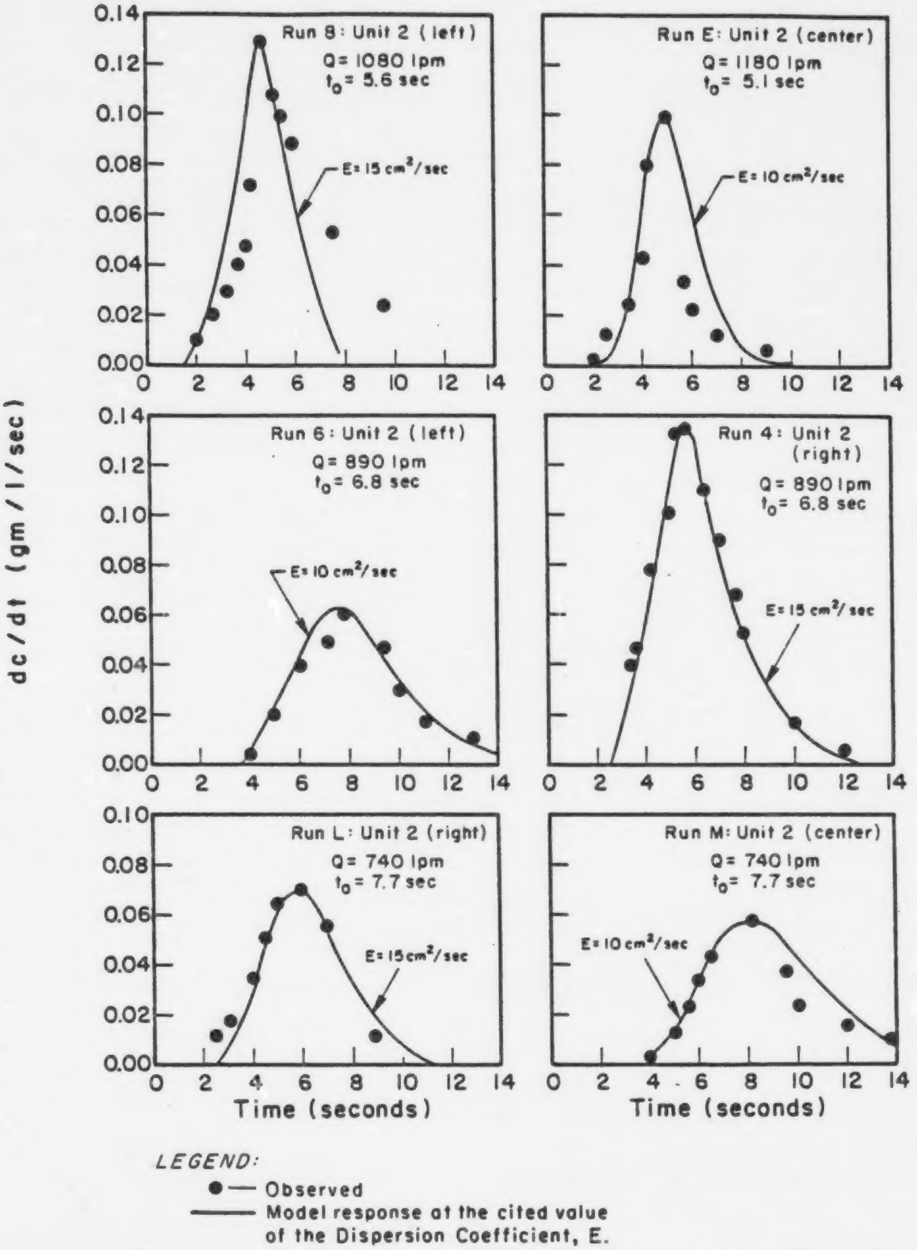
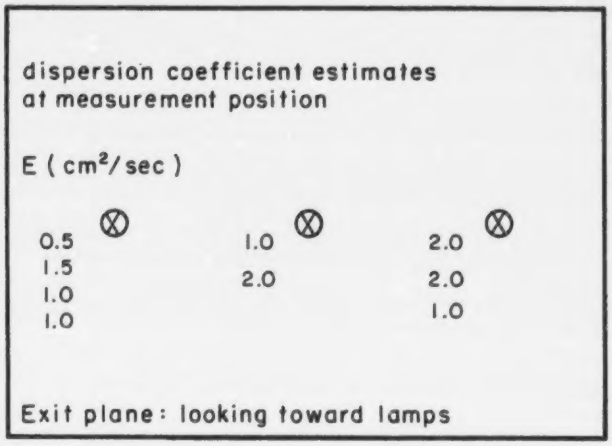


Figure 7-11. Dispersion curves and estimates of E for Unit 2.

Unit 1 (5.0 cm spacing)

E (cm^2 / sec)

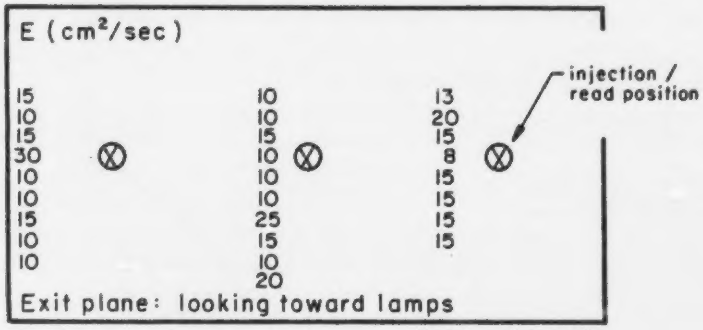
Flow (lpm)		
740	1390	1500
0.5	2.0	2.0
1.0	2.0	1.0
1.5		1.0
1.0		


dispersion coefficient estimates at measurement position
E (cm^2/sec)
0.5
1.5
1.0
1.0
1.0
2.0
2.0
2.0
1.0
Exit plane: looking toward lamps

Unit 2 (1.25 cm spacing)

E (cm^2 / sec)

Flow (lpm)			
740	810	1080	1180
13	25	15	10
20	15	15	10
10	8	10	15
10	15	20	10
15	10	15	10
10		5	10
			30
			10
			20
			15


E (cm^2/sec)
15
10
15
30
10
10
15
10
10
10
10
15
10
10
10
25
15
10
20
13
20
15
8
15
15
15
15
injection / read position
Exit plane: looking toward lamps

Note: not to scale

Figure 7-12. Summary figure of dispersion coefficients measured on Units 1 and 2.

Head Loss Measurements - Laminar/Turbulent Flow Estimates

Head loss measurements are plotted as a function of flow rate on the upper display of Figure 7-13. These are losses incurred by the lamp batteries only and do not reflect losses from inlet structures, etc. As would be expected, the larger losses are found for Unit 2 which has the more closely spaced lamp system. Even these losses, however, are relatively small with a differential of less than 4 cm at the highest flow rate tested, 2600 lpm. Unit 1 had a loss of less than 2 cm at an equivalent flow rate.

An important factor in the hydraulic design of a system (and an assumption in the use of the dispersion coefficient) is to maintain complete mix conditions under all operating flow rate changes in the plane perpendicular to the direction of flow. The criterion of having complete mix in the plane perpendicular to the direction of flow is described as being turbulent. The reason for this requirement is the non-uniformity of the UV intensity within the UV reactor. By assuring that water is turbulent as it moves (as a plug) through the reactor, the microorganisms are given the equal probability of being exposed to all intensity levels within the reactor. Conversely, if a laminar condition were to exist, there is the possibility of stratified exposure to the non-uniform intensity field.

The head loss data can be examined to estimate the laminar/turbulent characteristics of the two quartz units and to approximate the transitional flow rate when conditions pass from laminar to turbulent flow.(18) In pipe flow, the friction losses with increasing flow rate will show a marked increase as the flow regime passes from laminar to turbulent, and will subsequently increase at a higher rate. This jump can be shown by plotting the log head loss against the log of the fluid velocity. This is shown for Units 1 and 2 on the lower display of Figure 7-13. The transitional jump for Unit 2 is evident at a log velocity of 1.02 (10.47 cm/sec). This is equivalent to a flow rate of 1160 lpm. This is close to the transition point shown on the h_L versus flow plot.

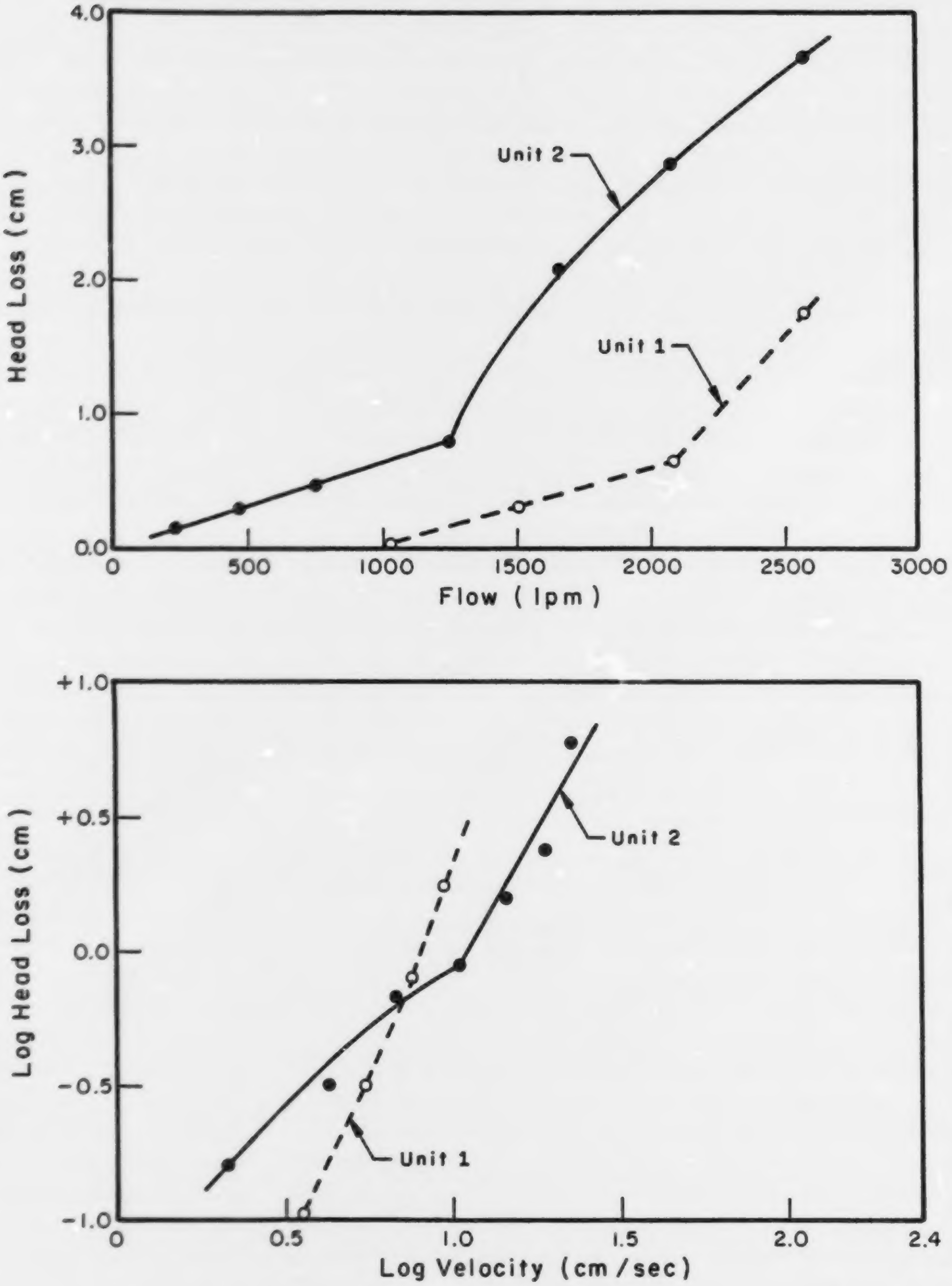


Figure 7-13. Head loss in lamp batteries of Units 1 and 2 and estimates of laminar/turbulent transition flows.

The transition is not as obvious on the log h_L - log velocity plot for Unit 1. However, from the upper display, the transitional flow rate can be estimated at 2070 lpm, which is equivalent to a velocity of 7.44 cm/sec (log velocity = 0.87). In all, these data indicate that although the dispersion coefficients were relatively low and indicated plug flow conditions, the second element of an ideal hydraulic design was not met. Under a large fraction of the operating flow range for both units, there was most likely laminar flow conditions rather than the desired turbulent flow. Greater unit length or staggered lamp arrangements may improve the turbulence of a system.

Hydraulic Conditions in Unit 3 (Teflon System)

Direct measurements of the teflon unit were not conducted during the Port Richmond study. The presumption can be made, however, that the design of the system inherently encourages plug flow. The teflon tubes effectively simulate pipe flow; Kramers and Westerterp(19) indicate that at aspect ratios in excess of 50 the flow is considered to be ideal plug flow. In this case the aspect ratio is defined as the ratio of the length to the hydraulic radius. For a pipe flowing full the hydraulic radius is 0.25 x diameter; thus for Unit 3 the hydraulic radius is 0.25 x 8.9 cm, or 2.22 cm. The length of the teflon tubes were 3 meters. The aspect ratio would, therefore, be 300 cm/2.22 cm, or 135.

Turbulence can also be demonstrated for the teflon tubes by estimating the Reynold's Number, N_R. This can be defined as:

$$N_R = DV/\nu$$

where:

D = Diameter
V = Velocity
ν = kinematic viscosity of the fluid

The Reynold's Number was calculated for a single teflon tube with a diameter of 8.9 cm and a length of 3 meters. The solution is graphically displayed on Figure 7-14. Typically the transition from laminar to turbulent flow conditions will occur at a Reynold's Number above 4000; laminar flow regions are generally at a Reynold's Number less than 2000. As shown on Figure 7-14 turbulent conditions will exist in the teflon tube at flow rates greater than 15 lpm. This is well below the normal operating range of the teflon system.

POWER REQUIREMENTS

Total power drawn by Units 1 and 2 was measured directly. The total power would then be divided by the average number of lamps in operation for that specific period. These data are presented on the upper display of Figure 7-15. As shown, the power draw was relatively constant with time; the variability reflects more the sometimes imprecise estimate of the number of lamps in actual operation. Overall, the power required averaged 47 watts/lamp. The nomimal power draw for these lamps (Voltarc G37T6VH) is 40 watts. The ballasts are high power factor with an estimated efficiency of 90 percent; thus the nominal requirement for the lamp/ballast would be approximately 44 watts. The additional 3 to 4 watts is likely due to miscellaneous line losses.

Power draw was not measured for the teflon unit. However, based on the information obtained regarding the quartz units, a good approximation would be 120 percent of the nominal lamp wattage.

ESTIMATION OF AVAILABLE UV ENERGY

An important element in the evaluation of a UV system's performance or in the design of a system is the actual energy available in the germicidal range. The low pressure mercury arc lamp emits approximately 40 percent of its nominal power draw as light; nearly 90 percent of this light emission is at the wavelength of 253.7 nm. This is the energy of interest for disinfection. The key is to understand how efficiently the 253.7 nm energy

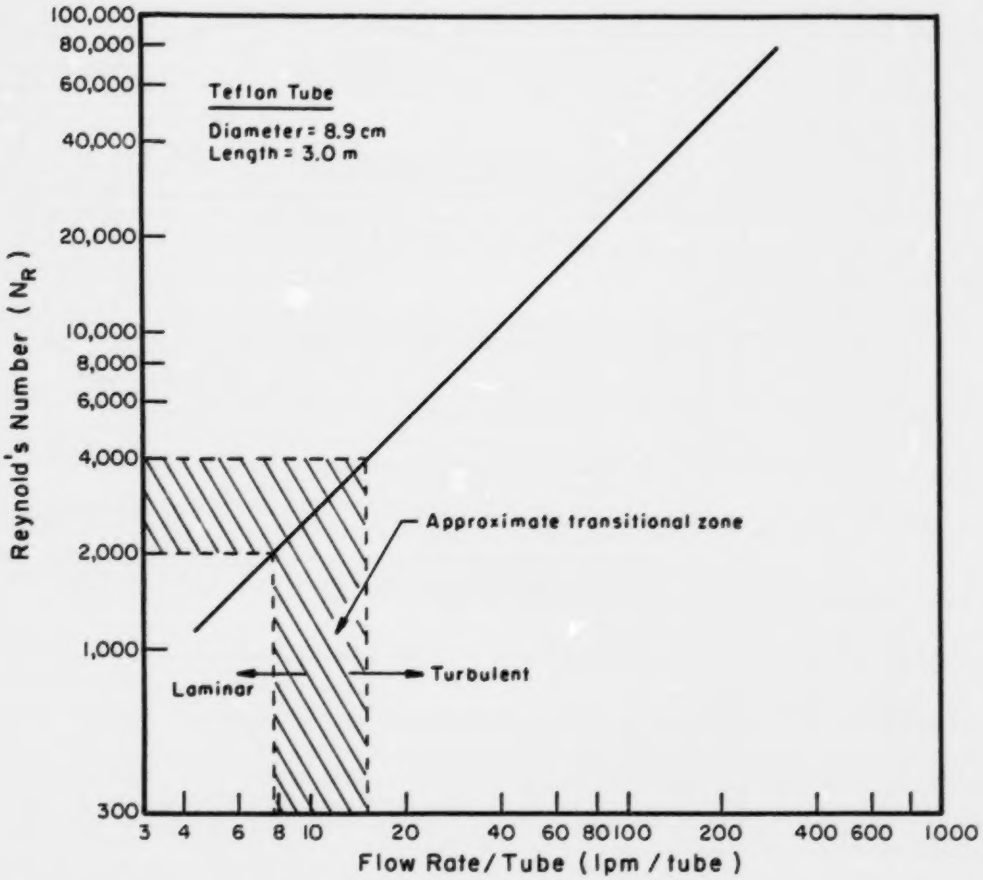


Figure 7-14. Estimates of Reynold's Number for 8.9 cm diameter teflon tubes.

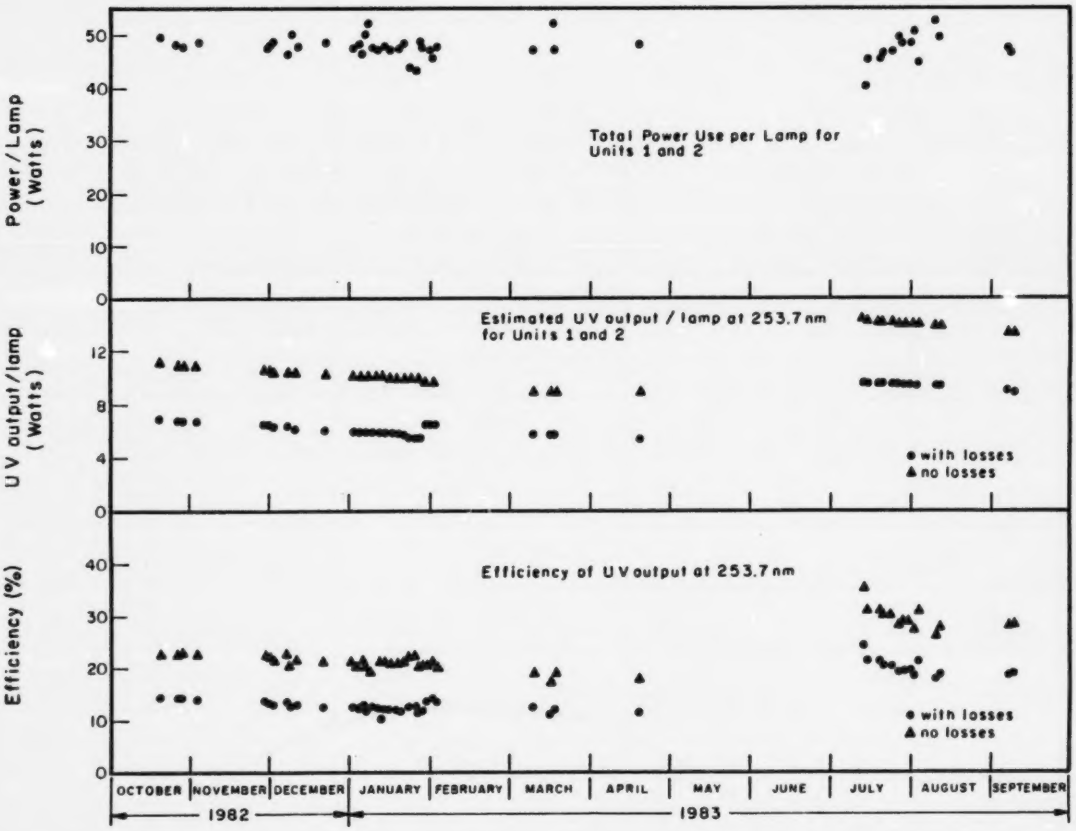


Figure 7-15. Chronological record of power use, UV output, and UV output efficiency for Units 1 and 2.

is being utilized and, conversely, how is it being lost. A considerable effort was expended during the study to directly monitor the output of the lamps and to quantify the amount of energy available for disinfection. These measurements centered on:

1. Output of the individual lamps at the 253.7nm wavelength
2. Loss of energy due to absorbance of the quartz sheath and the teflon tube, and
3. Loss of energy due to the fouling of surfaces through which the UV radiation must pass.

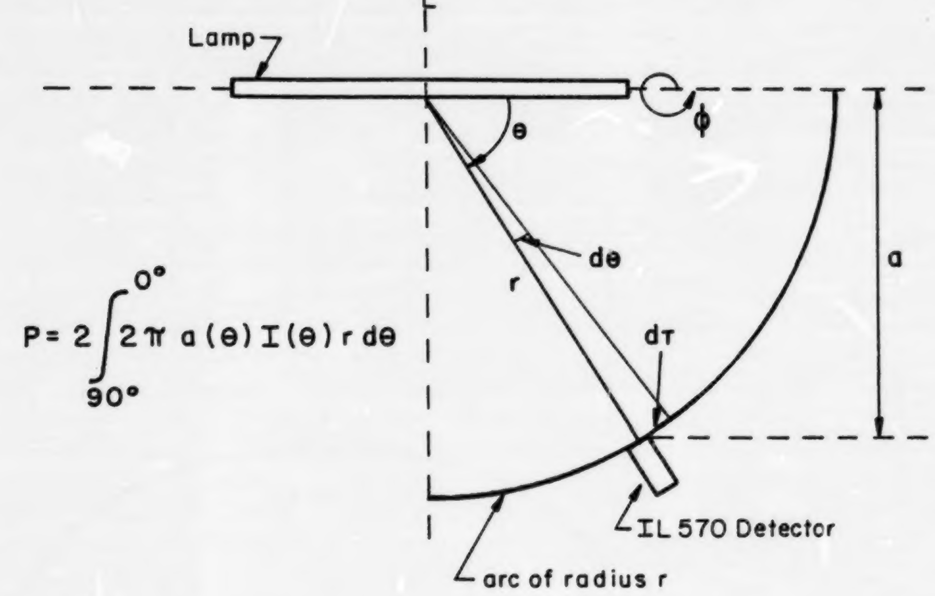
Measurement of Lamp Output

A major loss of UV energy is from the simple aging of the lamp. With use, the emission of the lamp at 253.7 nm will steadily decrease; this is rather sharp in the first few hundred hours, which is why the nominal UV output rating for a lamp is set after 100 hours burn time. The nominal UV output for the lamps used at Port Richmond was 14.3 watts at 100 hours.

Direct measurements were made to confirm this rated output and the output after a period of operation. The procedure was described in Section 5 and involved taking intensity readings along an arc scribed at a fixed radius from the center of the lamp. These readings would then be integrated over the surface of a sphere with the same radius. In effect the procedure treats the lamp as a single point source of light; this makes it important that the radius be long relative to the length of the lamp.

Figure 7-16 schematically presents the experimental setup to measure the total output and a sample analysis of a set of data. In radial space, the total power can be computed:

$$P = 2 \int_{90^{o}}^{0^{o}} \int_{0}^{2\pi} I_{T}\,(\theta)\; d\phi\; dT\,(\theta) \qquad (7\text{-}17)$$


℄
Lamp
θ
φ
dθ
r
a
dτ
IL 570 Detector
arc of radius r

$$P = 2\int_{90^\circ}^{0^\circ} 2\pi\, a(\theta)\, I(\theta)\, r\, d\theta$$

Measurement at r = 122 cm (7/21/83)
Bulb N-1-12

Angle θ	IL570 ($\mu W/cm^2$)
90°	87.
75°	85.5
60°	82.
45°	69.
30°	55.5
15°	24.

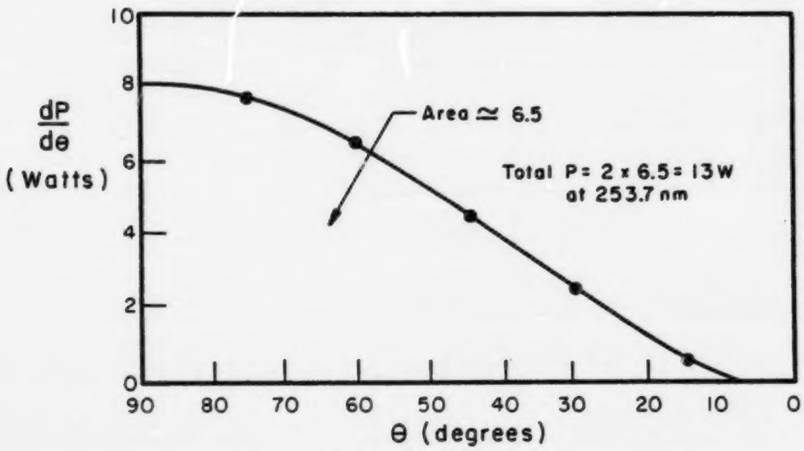


Figure 7-16. Measurements and analysis technique for estimating the total UV output of a lamp.

where:

P = the total power at 253.7 nm (watts)

θ = angle of the detector from the longitudinal centerline of the lamp (0 to 90 degrees)

ϕ = angle about the centerline of the lamp (0 to 360 degrees)

I = intensity reading at radius r at a point (T) along the arc

Since:

$$\int_{o}^{2\pi} I_T(\theta)\, d\phi = 2\pi\, a(\theta)\, I(\theta) \tag{7-18}$$

and:

$$dT(\theta) = rd\theta \tag{7-19}$$

then Equation (7-17) can be written:

$$P = 2 \int_{90^o}^{0^o} 2\pi\, a(\theta)\, I\, (\theta)\, rd\theta \tag{7-20}$$

This can be solved graphically by plotting $dP/d\theta$ against θ, as shown by the example on Figure 7-16. The area under the curve is power output at the wavelength 253.7nm, and represents one-half of the sphere about the lamp. Doubling this power estimate yields the total output of the lamp. The example shows that lamp N-1-12 had an estimated UV output of 13 watts.

A total of 9 lamps were measured by this method after 100 to 300 hours operation. The measured output ranged from 12.2 to 15.9 watts, with an average output of 13.6 watts which is close to the rated output of 14.3 watts given by the manufacturer.

A far simpler technique was employed to monitor the average lamp output with time. The setup with the lamp and the detector was the same as shown on Figure 7-16; in this case, however, a single reading was taken at θ

equal to 90 degrees and compared to the same intensity reading for a new lamp. This was done twice, in June 1983 and in September 1983.

In June 1983, every lamp was removed from Units 1 and 2, cleaned, and measured for relative output. These readings were compared to the measured average output of 10 new lamps. The results are shown on Table 7-8. The average operational time was approximately 8200 hours; the relative output averaged 60.2 percent for Unit 1 and 57.4 percent for Unit 2.

New lamps were purchased at this point, and two banks of lamps were relamped on each unit, for a total of 60 lamps per unit. At the end of the study these lamps were also tested for relative output, the results of which are presented on Table 7-9. Unit 1 had approximately 1500 hours service and an average relative output of 86 percent. Unit 2 had a relative output of 84 percent after approximately 1000 hours service.

TABLE 7-9. SUMMARY OF UV OUTPUT MEASUREMENTS FOR UNITS 1 AND 2

Distribution Relative to New Lamp Output (100 hrs)	Number of Lamps			
	June 1983 (average 8200 hrs)		September 1983	
	Unit 1	Unit 2	Unit 1 (1500 hrs)	Unit 2 (1000 hrs)
Greater than 90%	6	-	31	15
85-90%	2	-	8	18
80-85%	1	5	6	11
75-80%	5	4	-	2
70-75%	8	9	2	5
65-70%	7	7	8	1
60-65%	17	9	1	1
55-60%	13	15	1	1
50-55%	16	19	1	1
45-50%	16	16	-	-
40-45%	5	11	1	-
35-40%	3	5	1	-
Broken	1	1	-	5
Total Lamps	100	100	60	60
Weighted Average Output[a]	60.2%	57.4%	86%	87%

[a] Relative to new lamps.

Loss of Energy Due to Quartz and Teflon Absorbance

Relative output readings were taken with and without a new, clean quartz sheath in place to determine the energy loss affected by the quartz alone. The fused quartz sheaths are rated to have a UV transmissibility of greater than 90 percent at 253.7 nm. A total of 12 measurements were made on a randomly selected quartz. The average reduction in intensity measured when the quartz was put in place over the lamp was approximately 25 percent, with a range of 15 to 35 percent.

The additional loss of transmissibility (from the expected 90 percent) may be due in part to the ozone produced by the lamps. The lamps used at Port Richmond were made of fused quartz, which has a high transmittance at the 185 nm wavelength. In the presence of free oxygen, energy at this wavelength will produce ozone. Ozone, in turn, is a good absorber of energy at the 253.7 nm wavelength. Thus, with any production of ozone in the gap between the lamp and quartz sheath, it is likely that there would be a consequent absorption of UV energy.

A test was conducted to confirm this effect. Nitrogen gas was passed through the gap to purge any oxygen and prevent the generation of ozone. Relative readings of UV output were then taken and compared to a similar series of readings without the nitrogen purge. The tests were difficult to quantify, but they clearly showed an increase of 25 to 35 percent over the output without the nitrogen purge. This would suggest that elimination of the ozone would allow the expected quartz transmissibility of greater than 90 percent. Based on these observations, it would be beneficial to use lamp envelopes which do not transmit at 185 nm (e.g., vycor).

A number of tests were also conducted on a sample of the teflon tubes used in Unit 3 at Port Richmond. Intensity readings were taken with and without the teflon in place; these readings also evaluated the transmittance with the lamp on both the convex and concave side of the teflon. These data are shown on Figure 7-17. The results are not conclusive. There appears to be some apparent effect of the curvature of the teflon,

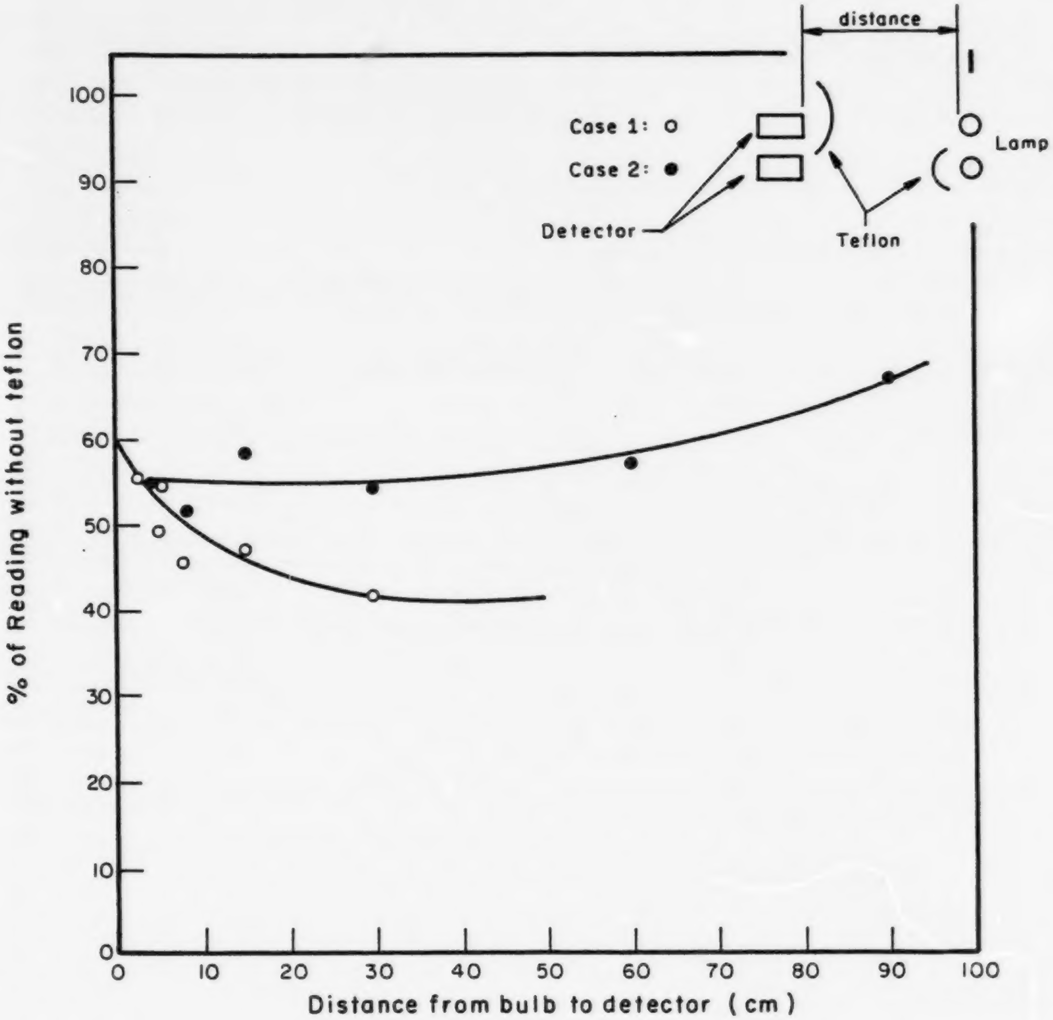


Figure 7-17. Estimate of teflon transmissibility.

with the higher transmittance measured when the lamp is on the inside of the teflon arc. The in-field configuration, however, is with the lamp outside the teflon tube; relatively low transmittances were measured for this arrangement. It is likely that the convex arc of the teflon reflects a portion of the UV light and does not allow transmittance into the liquid.

As shown, transmittances as low as 42 percent were measured. This does not correspond to the expected 75 percent transmittance claimed by the manufacturer.

It is difficult, at this point, to estimate the actual transmittance of the teflon at any given time. Based on the results of this study, approximations were made to reflect the conditions observed in the unit and to determine the effective UV wattage reaching the liquid:

Operating time:

8/23/82 to 9/1/82	The teflon was new at this time; the transmittance was assumed to be at the manufacturers rating of 75 percent.
3/15/83 to 3/17/83	This was the startup of the newly refurbished compartment 1 after one month. A transmittance of 60 percent was assumed.
3/28/83 and 3/29/83	A transmittance of 50 percent was used. This level is felt to be representative, based on direct measurements of clean used teflon.
4/14/83	The transmittance was reduced to 40 percent to reflect 4 weeks continuous operation.
4/21/83 to 4/27/83	A transmittance of 30 percent was used to reflect approximately two months operation without cleaning. This is similar to levels directly measured at a second plant using the teflon system under similar conditions.(20)
8/22/83 to 8/24/83	A transmittance of 50 percent was used to reflect the system cleaning just prior to this period.

These teflon transmittance levels were then coupled with the estimated lamp output as a function of operating time (these are discussed relative to Figure 7-19) to approximate the actual output/lamp reaching the fluid. These are presented on Figure 7-18. Note that the outputs were adjusted for the 1982 data to account for the smaller diameter tubes. All the data on Figure 7-18 are normalized to the use of 8.9 cm diameter teflon tubes.

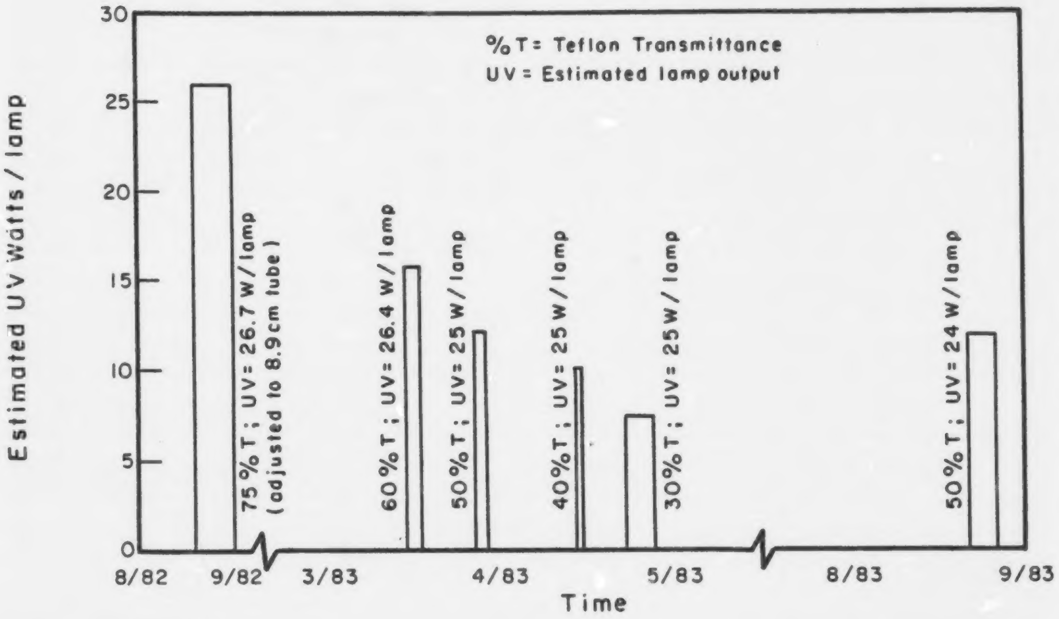


Figure 7-18. Estimated UV output/lamp for Unit 3 accounting for aging and teflon loss.

Effect of Fouling on UV Output

Earlier discussions in this section described the cleaning tasks conducted on the quartz systems to restore the lamp and quartz surfaces. When these tasks were accomplished, the IL570 Radiometer was used to estimate the effect of the fouling (and subsequent cleaning) on the relative output of the system. The cleaning was directed to the lamp surfaces and the inside and outside surface of the quartz sheaths.

The lamp surfaces were cleaned before they were reinstalled in the units. Although a small number of the lamps were visibly dirty, it was found that lamp surfaces remained relatively clean and had only a negligible effect on the system's UV output. The cause of the few lamps that did get dirty was typically leakage of water from the quartz seals.

A number of quartz were removed from the system to determine the relative effects of cleaning the inside and outside surfaces. Table 7-10 shows the results of one such series of tests. The unit was first cleaned with an acid and detergent solution per the routine procedure for the study. The quartz were then removed from the unit and tested for transmittance relative to a new, clean quartz sheath. These data are summarized in Table 7-10. The intensity readings taken immediately after the quartz were removed from the unit averaged 61.6 μWatts/cm^2 which is 81.6 percent the reading obtained with a new quartz sheath. Cleaning the inside surface of the quartz sheaths improved the output to 70.1 μWatts/cm^2, or 92.8 percent of the new quartz reading. Lastly, the output increased to 75.3 μWatts/cm^2 when the outer surfaces were cleaned, which was essentially equivalent to the new quartz reading.

TABLE 7-10. EFFECTS OF FOULING ON THE UV TRANSMITTANCE OF QUARTZ

	Intensity Readings[a]					
Tube Number	After Removal from Unit[b] (μWatts/cm^2)	Relative to New Quartz	Cleaned Inside of Quartz (μWatts/cm^2)	Relative to New Quartz	Cleaned Outside of Quartz (μWatts/cm^2)	Relative to New Quartz
4	50.5	66.9%	66.5	88.1	77.5	102.6%
34	60.5	80.1%	67.5	89.4	73.5	97.3%
64	63.5	84.1%	70.5	93.4	74.0	98.1%
74	68.5	90.7%	73.5	97.3	73.5	97.3%
84	66.5	88.1%	73.5	97.3	72.5	96.0%
94	60.0	79.5%	69.0	91.4	81.0	107.3%
Average	61.5	81.6%	70.1	92.8%	75.3	99.8%

[a] Intensity of bulb without quartz is 90.5 μWatts/cm^2 at 1.2 m. The intensity with a new quartz in place is 75.5 μWatts/cm^2. This is used as the reference intensity.
[b] Cleaned by acid/detergent solution while in the unit.

The inside of the quartz had last been cleaned five months before these readings; for subsequent estimates the output was presumed to decrease at the rate of 10 percent each five months due to fouling of the inside surface. The outside surface was cleaned by the acid/detergent solution procedure each time the unit was to be sampled. The results presented in Table 7-10 indicate that although this procedure is quite effective, there is apparently a film which stays on the surface; this was presumed to cause a loss of approximately eight percent of the UV output at any time.

Summary - Estimation of UV Output Efficiency With Time

An estimate was made of the actual UV output per lamp (on average) for Units 1 and 2, based on the information presented above. Figure 7-19 presents a summary analysis of these data:

1. The manufacturer's nominal lamp rating of 14.3 watts at 253.7 nm is presumed as the average nominal rating for all lamps used in Units 1 and 2. The manufacturer's estimated decay of output with time is also shown; this shows an output of approximately 70 percent at 7500 hours.

2. A straight line approximation is made to account for the decay of the lamp's output between 0 and 8200 hours, based on the direct measure of the lamps' average relative output.

3. A constant 25 percent loss of energy is assumed to account for quartz sheath absorbance, and losses attributable to ozone absorbance, temperature effects, and other operating effects within the air gap between the lamp and quartz sheath.

4. A constant eight percent loss is taken to account for the film layer on the outer surface of the quartz sheaths. This appeared to be a "steady state" condition which developed, even with repeated acid/detergent washings of the lamp batteries. The eight percent loss is appropriate for the Port Richmond units since the systems were cleaned before the days samplings were accomplished. This loss may be larger in actual

full scale installations and may progressively increase with time between chemical cleaning cycles.

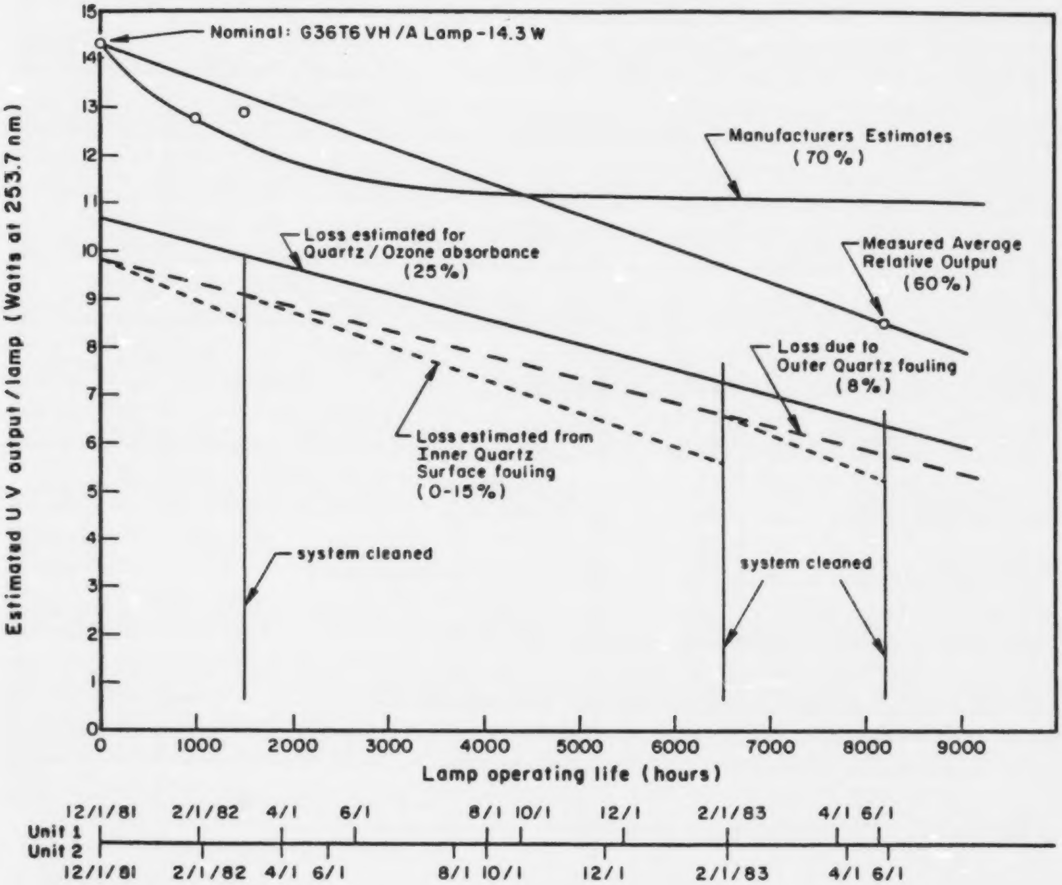


Figure 7-19. Approximation of average lamp UV output at 253.7 nm with time.

5. The final adjustment made to the lamp output was to account for the loss incurred by the fouling of the inside of the quartz sheaths. This was felt to be a progressive occurence; the loss was applied at a rate of 15 percent per five months in the periods between the times the quartz surfaces were cleaned.

The lower line, therefore, is an estimate of the actual average UV output for the lamps at any time during the experimental period of the study. The approximate calendar date corresponding to the time of operation for either Units 1 or 2 is also shown. Note that the period July to September 1983 would correspond to the initial 1500 hours of operation.

Returning to Figure 7-15, the analysis presented on Figure 7-19 is shown as a chronological record of actual average UV output per lamp, with and without losses. This is also shown in terms of actual efficiency of power use. Nominally, an efficiency of approximately 30 percent is expected; this will decrease to approximately 20 percent of total power required simply due to the aging of the lamps. When other losses are accounted for, however, it can be seen that the power actually available for disinfection purposes is reduced to between 20 percent of total power with relatively new lamps, and 10 percent with approximately one year of operating time.

UV SYSTEM PROCESS PERFORMANCE IN THE TREATMENT OF SECONDARY EFFLUENT

A major objective of the Port Richmond study was to determine the effectiveness of the UV systems in the inactivation of total and fecal coliforms under varying water quality and operating conditions. This effectiveness was evaluated by performing a series of multiple linear regression analyses to correlate performance with the operation of the unit and with the quality of the Port Richmond secondary effluent. A population of approximately 200 samplings was available for these analyses. The multiple linear regression is computed by the method of least squares; the regression is calculated in a stepwise fashion, ordering the independent variants by decreasing degree of significance. It should be understood that such analyses are purely empirical in nature and reflect only the interactions of the specific unit designs evaluated at Port Richmond. It is generaly not appropriate to extend these regressions to wholly different unit configurations or wastewater characteristics, although they can serve as first cut approximations of performance.

The dependent variable in all cases was the log of the survival ratio (Log L/L_o) for either total or fecal coliforms. The independent variables which were tested to reflect wastewater quality were the suspended solids, turbidity, and either the direct or the spherical UV absorbance coefficients at the 253.7 nm wavelength (α_D and α_S, respectively, in cm^{-1}, base e). The COD was tested, but was not found to be effective.

The variant selected to reflect the operating condition of the particular unit was the ratio of the flow rate to the estimated total UV output at 253.7 nm at the time of sampling. This ratio, Q/W, has the units lpm/watt, where watt is the power output at 253.7 nm. This parameter was selected as one that is accessible, is easily computed, and can be utilized to compare alternative systems and to size systems. It reflects the earlier discussions of the key parameters in the design of a UV system: exposure time and intensity. The flow rate will set the time for a given unit configuration while the UV output will be a measure of the energy delivered to the wastewater.

Understand that the ratio Q/W should only be used as it is intended; as an empirical measure of a unit's operating mode. It does not account for dispersion within a system and the corresponding distribution of time, nor does it reflect the actual intensity of UV radiation in a system. It is appropriate to use as a descriptor of a single system, and in conjunction with some measure of the wastewater quality. In the case of a side by side evaluation of two (or more) systems in the treatment of a single plant effluent, such as the Port Richmond study, the ratio can be a good indexing parameter to compare system performance. As an example, System A may require a Q/W of 2.0 to acheive a Log L/L_o of -3, while System B can achieve the same performance at a ratio of 3.0. The ratio itself cannot explain why the systems would require different sizings, but it does provide a useful measure for comparison.

The flow rate Q is that measured at the time of sampling. The UV output, W, is estimated based on the number of lamps in operation at the time of sampling and the estimated average lamp output at the time. This average lamp output, which takes into account the energy losses associated with the aging of the lamp and the transmittance through the quartz or teflon, was discussed in an earlier section. For the quartz units (1 and 2), Figure 7-19 presents the estimated output per lamp as a function of cumulative lamp operating time, and Figure 7-15 presents the estimate as a function of chronological time. A similar analysis is presented for the teflon unit (Unit 3) on Figure 7-18. Understand that this UV output is at the 253.7 nm wavelength.

Regression Equations

Tables 7-11 and 7-12 present a summary of the regression equations derived for Units 1 and 2 (quartz systems) for total and fecal coliforms, respectively. The regression equations derived for total and fecal coliforms on Unit 3 are presented in Table 7-13. The tables present the independent variables tested, the equation for either unit with these variables, and the coefficient of determination, r^2, for the regression equation. This coefficient is the square of the correlation coefficient, r, and is a measure of the variance which is explained by the regression equation. Thus, as an example, an r^2 of 0.50 suggests that approximately 50 percent of the variation observed for the dependent variable can be explained by the variation of the independent variables.

Regression Equations for the Quartz Systems (Units 1 and 2)--

Regression of Log L/L_o with Q/W--The most significant variable was the ratio Q/W, which correlated well with the Log L/L_o for either the fecal or total coliform. The r^2 ranged between 0.34 and 0.4. Thus, greater than one-third the variance observed for the Log L/L_o could be explained by the operation of the UV system itself.

Regression of Log L/L_o with Q/W and the UV Absorbance Coefficient--The addition of either the direct or spherical absorbance coefficient in a multiple linear regression with Q/W improved the correlation appreciably. The value of r^2 was increased to between 0.42 and 0.47 for regression of the log survival ratio with Q/W and the spherical absorbance, α_S. The

TABLE 7-11. SECONDARY EFFLUENT TOTAL COLIFORM - UNITS 1 AND 2 STEPWISE MULTIPLE LINEAR REGRESSION ANALYSES TO DETERMINE THE CORRELATION OF THE LOG COLIFORM SURVIVAL RATIO WITH SYSTEM OPERATION AND WASTEWATER QUALITY

Independent Variables[a]	Unit Number	Regression Equation ($\log L/L_o =$)	r^2[g]
Q/W[b]	1	0.294 (Q/W) - 4.19	0.36
	2	0.317 (Q/W) - 4.23	0.40
Q/W and α_s[c]	1	0.297 (Q/W) + 2.78 (α_s) - 5.17	0.44
	2	0.319 (Q/W) + 1.94 (α_s) - 4.90	0.42
Q/W and SS[d]	1	0.329 (Q/W) + 0.0346 (SS) - 4.76	0.51
	2	0.344 (Q/W) + 0.031 (SS) - 4.72	0.49
Q/W and Turbidity[e]	1	0.292 (Q/W) - 0.0014 (Turb) - 4.18	0.36
	2	0.323 (Q/W) - 0.0043 (Turb) - 4.24	0.41
Q/W; α_s; SS	1	0.33 (Q/W) + 0.033 (SS) + 2.40 (α_s) - 5.58	0.57
	2	0.345 (Q/W) + 0.029 (SS) + 1.64 (α_s) - 5.26	0.50
Q/W; α_s; Turbidity	1	0.296 (Q/W) + 2.78 (α_s) + 0.0016 (Turb) - 5.18	0.44
	2	0.327 (Q/W) + 2.04 (α_s) + 0.0043 (Turb) - 4.95	0.43
Q/W; α_s; SS; Turbidity	1	0.327 (Q/W) + 0.033 (SS) + 2.40 (α_s) - 0.0028 (Turb) - 5.58	0.57
	2	0.351 (Q/W) + 0.028 (SS) + 1.72 (α_s) - 0.0033 (Turb) - 5.29	0.50
Q/W; α_D[f]	1	0.351 (Q/W) + 2.57 (α_D) - 5.37	0.46
	2	0.338 (Q/W) + 2.11 (α_D) - 5.19	0.45
Q/W; α_D; SS	1	0.334 (Q/W) + 0.027 (SS) + 1.56 (α_D) - 5.36	0.55
	2	0.349 (Q/W) + 0.024 (SS) + 1.13 (α_D) - 5.13	0.49

[a] Variables appear in order of importance to the correlations.

[b] Ratio of flow rate to the total UV output of the system (lpm/Watt of 253.7 nm).

[c] α_s is the base e absorbance coefficient at 253.7 nm (cm^{-1}), corrected for scatter.

[d] Suspended solids in mg/l.

[e] Turbidity in NTU.

[f] α_D is the base e absorbance coefficient at 253.7 nm (cm^{-1}) uncorrected for scatter.

[g] The square of the correlation coefficient, r, is an estimate of the variance explained by the regression.

TABLE 7-12. SECONDARY EFFLUENT FECAL COLIFORM - UNITS 1 AND 2
STEPWISE MULTIPLE LINEAR REGRESSION ANALYSES TO DETERMINE THE CORRELATION
OF THE LOG COLIFORM SURVIVAL RATIO WITH SYSTEM OPERATION AND WASTEWATER QUALITY

Independent Variables[a]	Unit Number	Regression Equation ($\log L/L_o =$)	r^2[g]
Q/W[b]	1	0.270 (Q/W) - 4.16	0.36
	2	0.285 (Q/W) - 4.19	0.34
Q/W and α_s[c]	1	0.277 (Q/W) + 2.93 (α_s) - 5.21	0.47
	2	0.294 (Q/W) + 2.69 (α_s) - 5.15	0.43
Q/W and SS[d]	1	0.313 (Q/W) + 0.0343 (SS) - 4.77	0.54
	2	0.315 (Q/W) + 0.0318 (SS) - 4.7	0.44
Q/W and Turbidity[e]	1	0.264 (Q/W) + 0.097 (Turb) - 4.52	0.51
	2	0.284 (Q/W) + 0.0902 (Turb) - 4.50	0.44
Q/W; α_s; SS	1	0.315 (Q/W) + 0.032 (SS) + 2.44 (α_s) - 5.59	0.61
	2	0.321 (Q/W) + 0.029 (SS) + 2.52 (α_s) - 5.56	0.51
Q/W; α_s; Turbidity	1	0.274 (Q/W) + 2.93 (α_s) + 0.0016 (Turb) - 5.21	0.47
	2	0.302 (Q/W) + 2.76 (α_s) + 0.0047 (Turb) - 5.20	0.44
Q/W; α_s; SS; Turbidity	1	0.309 (Q/W) + 0.028 (SS) + 2.4 (α_s) + 0.0396 (Turb) - 5.59	0.62
	2	0.322 (Q/W) + 0.019 (SS) + 2.37 (α_s) + 0.0425 (Turb) - 5.52	0.52
Q/W; α_D[f]	1	0.299 (Q/W) + 2.63 (α_D) - 5.4	0.49
	2	0.317 (Q/W) + 2.47 (α_D) - 5.36	0.46
Q/W; α_D; SS	1	0.321 (Q/W) + 0.26 (SS) + 1.64 (α_D) - 5.46	0.58
	2	0.328 (Q/W) + 1.89 (α_D) + 0.021 (SS) - 5.42	0.49

[a] Variables appear in order of importance to the correlations.

[b] Ratio of flow rate to the total UV output of the system (lpm/Watt of 253.7 nm).

[c] α_s is the base e absorbance coefficient at 253.7 nm (cm^{-1}), corrected for scatter.

[d] Suspended solids in mg/l.

[e] Turbidity in NTU.

[f] α_D is the base e absorbance coefficient at 253.7 nm (cm^{-1}) uncorrected for scatter.

[g] The square of the correlation coefficient, r, is an estimate of the variance explained by the regression.

TABLE 7-13. SECONDARY EFFLUENT TOTAL AND FECAL COLIFORM - UNIT 3 STEPWISE MULTIPLE LINEAR REGRESSION ANALYSES TO DETERMINE THE CORRELATION OF THE LOG COLIFORM SURVIVAL RATIO WITH SYSTEM OPERATION AND WASTEWATER QUALITY

Independent Variables[a]	Regression Equation ($\log L/L_o =$)	r^2 [b]
Total Coliform		
Q/W	1.03 (Q/W) - 4.88	0.61
Q/W and α_S[c]	1.02 (Q/W) + 2.98 (α_S) - 5.83	0.64
Q/W and α_D[c]	1.01 (Q/W) + 1.59 (α_D) - 5.44	0.65
Q/W and SS[d]	0.97 (Q/W) + 0.014 (SS) - 4.91	0.62
Q/W and α_S and SS	0.98 (Q/W) + 2.65 (α_S) + 0.0097 (SS) - 5.75	0.65
Q/W and α_D and SS	0.97 (Q/W) + 0.011 (SS) + 1.22 (α_D) - 5.33	0.63
Fecal Coliform		
Q/W	1.0 (Q/W) - 4.83	0.64
Q/W and α_S	0.99 (Q/W) + 3.24 (α_S) - 5.86	0.68
Q/W and α_D	1.0 (Q/W) + 1.84 (α_D) - 5.47	0.65
Q/W and SS	0.95 (Q/W) + 0.013 (SS) - 4.86	0.65
Q/W and α_D and SS	0.96 (Q/W) + 2.99 (α_S) + 0.0076 (SS) - 5.80	0.68
Q/W and α_D and SS	1.0 (Q/W) + 1.54 (α_D) + 0.0091 (SS) - 5.39	0.66

[a] Variables appear in order of decreasing significance.

[b] Coefficient of determination.

[c] α_S and α_D are the base e UV absorbance coefficients (cm^{-1}) by the spherical and direct methods, respectively.

[d] Suspended solids, mg/l

direct absorbance coefficient, α_D, also provided a significant correlation, increasing the value of r^2 to between 0.45 and 0.49.

Regression of Log L/Lo with Q/W and Suspended Solids or Turbidity--Coupling the Q/W with a measure of the particulates, i.e., the suspended solids or the turbidity, also significantly improved the correlation. The suspended solids were found to be more effective than the turbidity, and yielded r^2 values very similar to r^2 of the Log L/Lo vs Q/W and α_D regression, ranging between 0.44 and 0.51.

Regression of Log L/L_o with Q/W, UV Absorbance Coefficient, and the Suspended Solids or Turbidity--Better correlations were accomplished when both the UV absorbance coefficient and the suspended solids were coupled with the Q/W to predict the Log L/L_o. Using the spherical absorbance coefficient yielded slightly stronger correlations than those with the direct absorbance coefficient. The value of r^2 for the regression of Log L/L_o against the Q/W, suspended solids and α_S ranged between 0.5 and 0.61. The analyses also suggested that the suspended solids were more significant than the UV absorbance coefficient in constructing the regression expression.

Substituting the turbidity for the suspended solids improved the correlation, but only slightly. In this case the UV absorbance coefficient was found to be the more significant variable, next to the ratio Q/W.

Regression of Log L/L_o with Q/W, UV Absorbance Coefficient, Suspended Solids, and Turbidity--When all independent variables were regressed against the Log L/L_o, the turbidity was found to be not significant. As shown in Tables 7-11 and 7-12, there was effectively no change in the correlation.

Regression Equations for the Teflon Unit (Unit 3)--

Before reviewing the regressions constructed for the teflon unit, it is important to understand the calculated UV output values used to compute the Q/W ratio. The actual UV watts available to the fluid were estimated, in similar fashion to the quartz systems, on the basis of lamp output and the estimated transmissibility of the teflon at the time of sampling. These values are presented on Figure 7-18.

A second manipulation was necessary, however, to normalize the output to a set number of teflon tube rows. For each sampling, the total available UV wattage was first computed and converted to the unit Watts/meter of lamp arc on the basis of the number of lamps in operation at the time. The meters of arc required for each meter of teflon tube will vary with the number of vertical tube rows in the system. This is shown on Figure 7-20 where N is the number of vertical tube rows for the system. The number of lamp rows required would be N+1. Thus, if the system has only one row of tubes, two rows of lamps would be required, yielding the ratio of 2 m arc/m tube. All of the 1983 data collected at Port Richmond were with two rows of tubes, which used 1.5 m arc/m of tube.

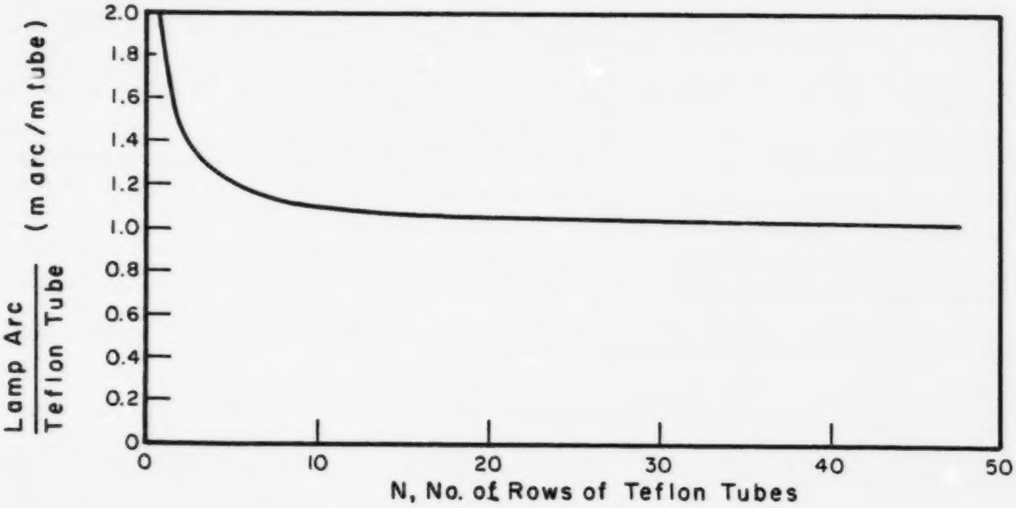


Figure 7-20. Effect of teflon system sizing on the power requirement efficiency.

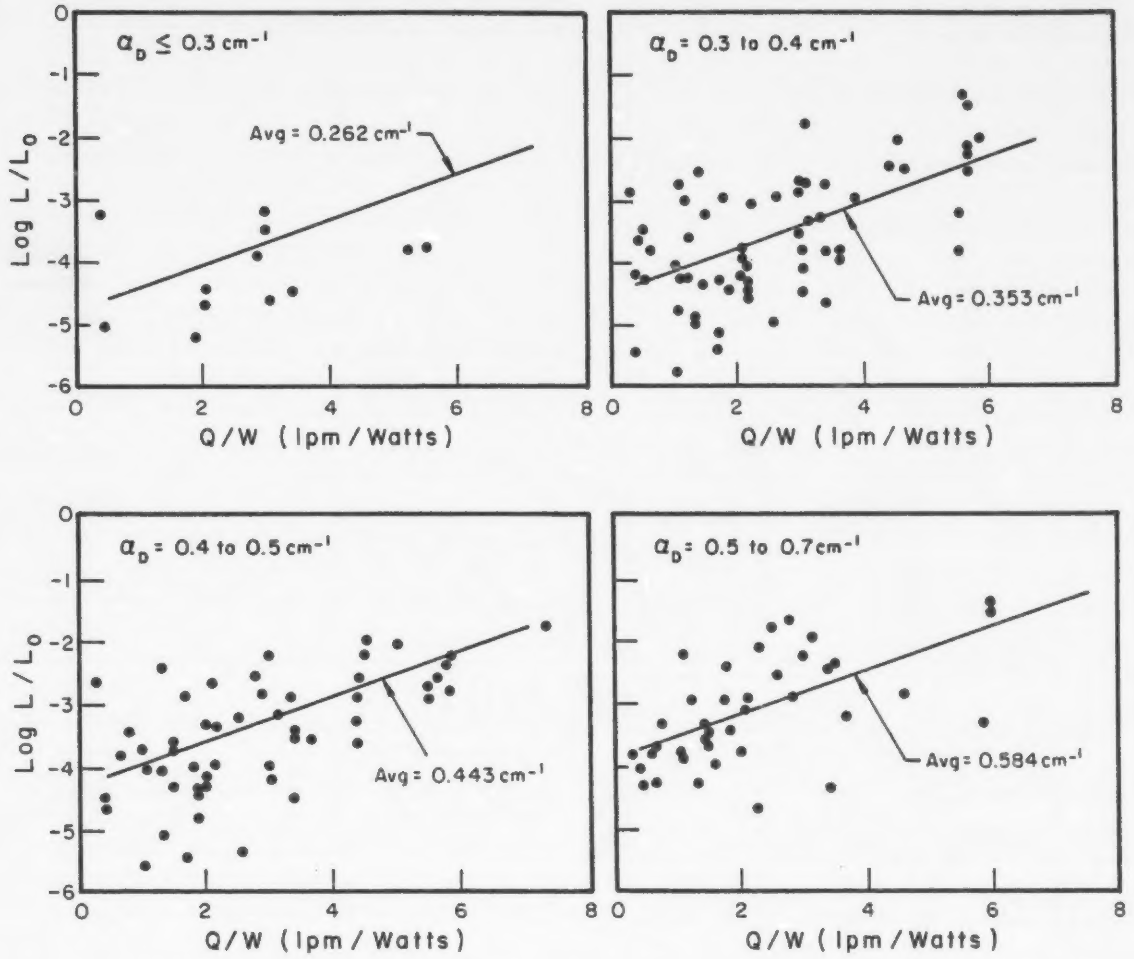
As N becomes larger, the ratio approaches 1.0. As shown on the figure, the greater efficiency is achieved on systems with greater than 10 teflon tube rows. The use of power is far less efficient on the smaller (one to five rows) systems.

For the sake of consistency, the data for Port Richmond was normalized to a system with 10 tube rows ($N = 10$). The total UV wattage available was computed on the basis of having 1.1 m arc/m of teflon tube. The diameter of the teflon tubes in all cases is 8.9 cm.

As shown in Table 7-13, the strongest correlation of Log L/L_o for total and fecal coliforms was with the ratio Q/W. The coefficient of determination was 0.635 and 0.61 for fecal and total coliform, respectively. Only marginal improvements were made by adding the water quality parameters in a multiple linear regression analysis. This is likely due to the already strong correlation with the Q/W, the limited data set, and the narrow range of values observed for the water quality data.

Summary of Performance Analysis for Units 1 and 2 (Quartz Systems) and Unit 3 (Teflon System)

The variables selected for subsequent analysis to demonstrate the performance of the quartz systems are the ratio Q/W, the direct and spherical UV absorbance coefficients, and the suspended solids. In order to effectively display the performance data obtained for each of the units, the regression equations of Log L/L_o as a function of the Q/W and the direct absorbance coefficient were used. The data were first segregated to subsets defined by ranges of the measured UV absorbance coefficient: α_D (base e) = less than 0.3 cm^{-1}; 0.3 to 0.4 cm^{-1}; 0.4 to 0.5 cm^{-1}; and 0.5 to 0.7 cm^{-1}. Each of these four subsets of data are displayed on Figures 7-21 and 7-22 for Unit 1 total coliform and Unit 1 fecal coliform, respectively. Figures 7-23 and 7-24 display the data for Unit 2 total and fecal coliforms, respectively. The plots show the Log L/L_o as a function of the ratio Q/W for each subset range of absorbance coefficients. Superimposed on these figures are the solutions to the regression equations developed for Log L/L_o as a function of Q/W and α_D:



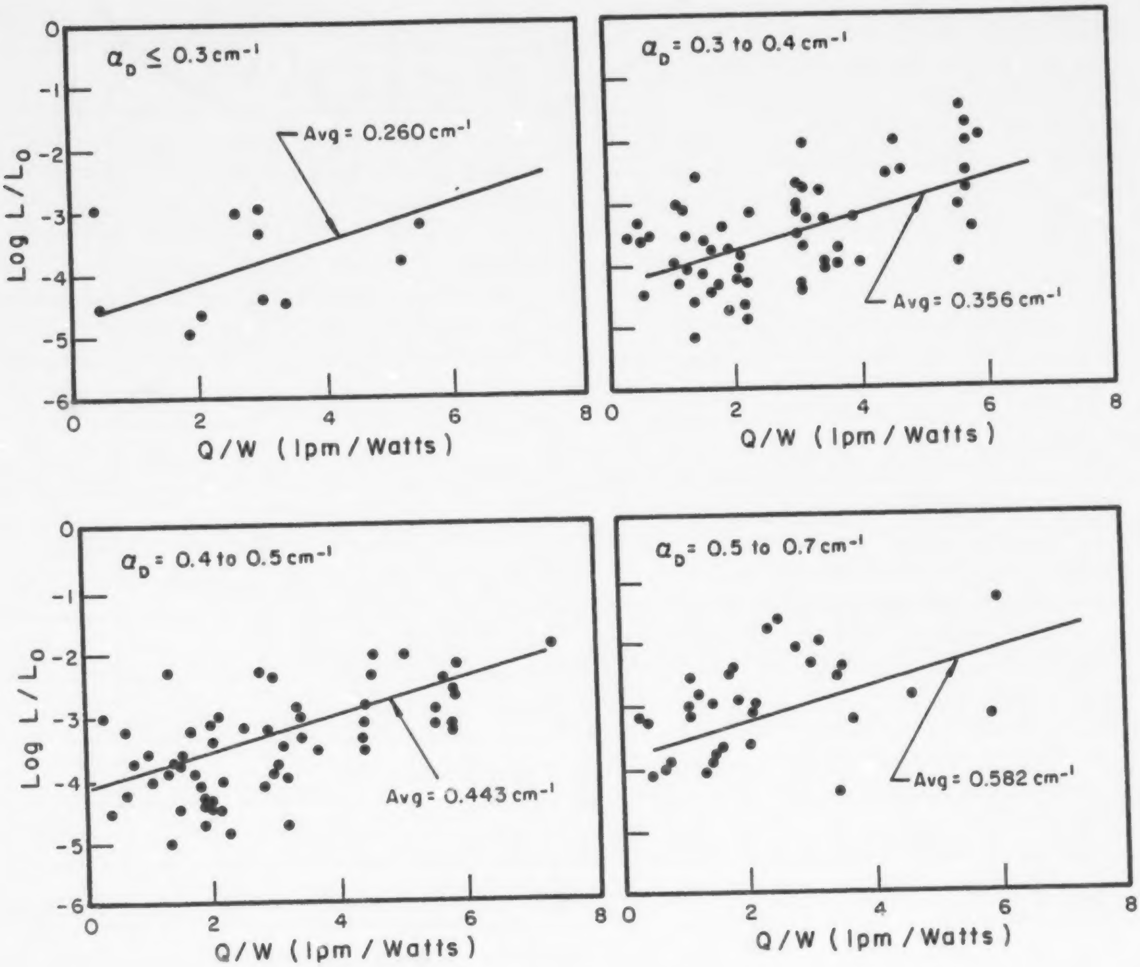
Equation for total coliform, Unit 1:

$$\text{Log } L/L_o = 0.351\ (Q/W) + 2.57\ (\alpha_D) - 5.37$$

Q/W = flow/watt of UV output at 253.7 nm

α_D = direct UV absorbance coefficient, base e, at 253.7 nm

Figure 7-21. Presentation of Unit 1 performance data for total coliform as a function of Q/W and the UV absorbance coefficient.



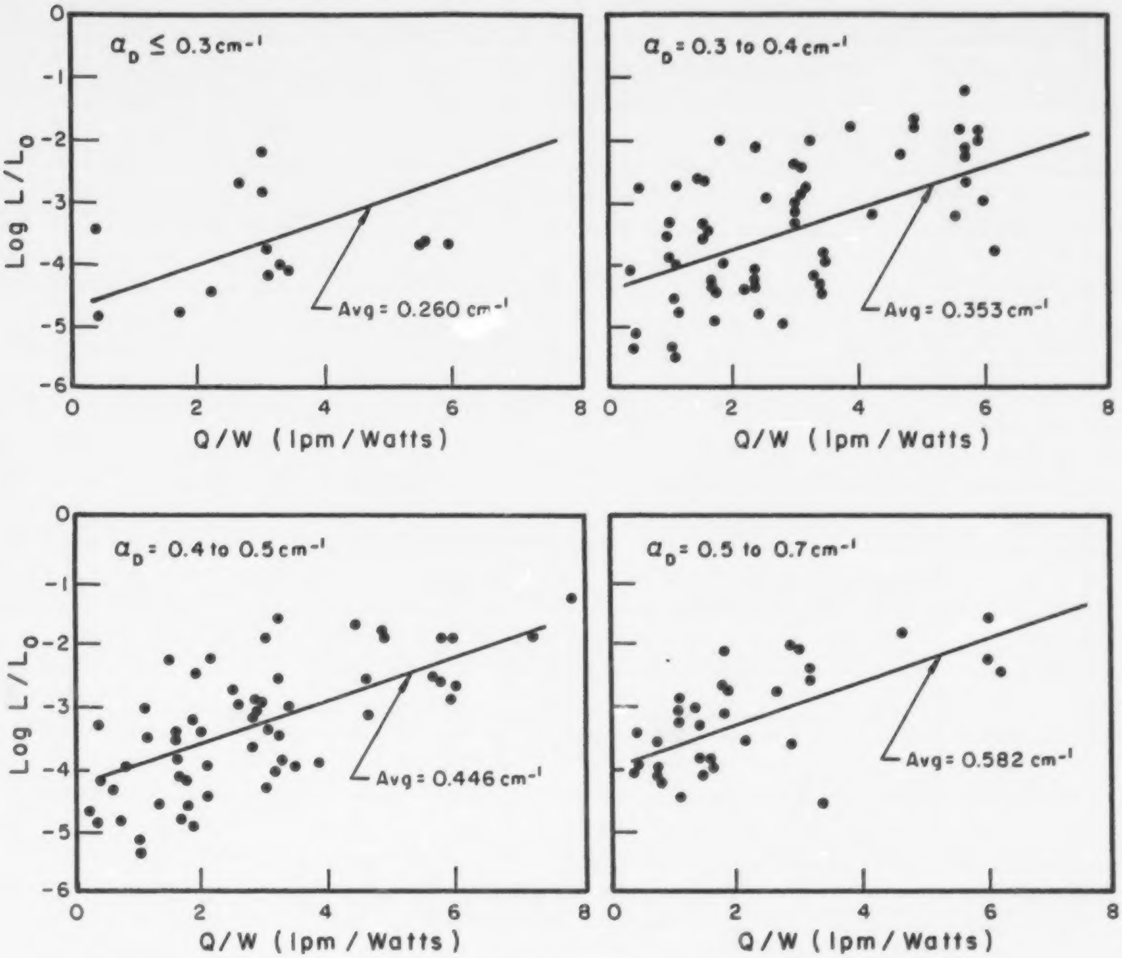
Equation for fecal coliform, Unit 1:

$$\text{Log } L/L_o = 0.299\ (Q/W) + 2.63\ (\alpha_D) - 5.4$$

Q/W = flow/watt of UV output at 253.7 nm

α_D = UV absorbance coefficient, base e, at 253.7 nm (direct method)

Figure 7-22. Presentation of Unit 1 performance data for fecal coliform as a function of Q/W and the UV absorbance coefficient.



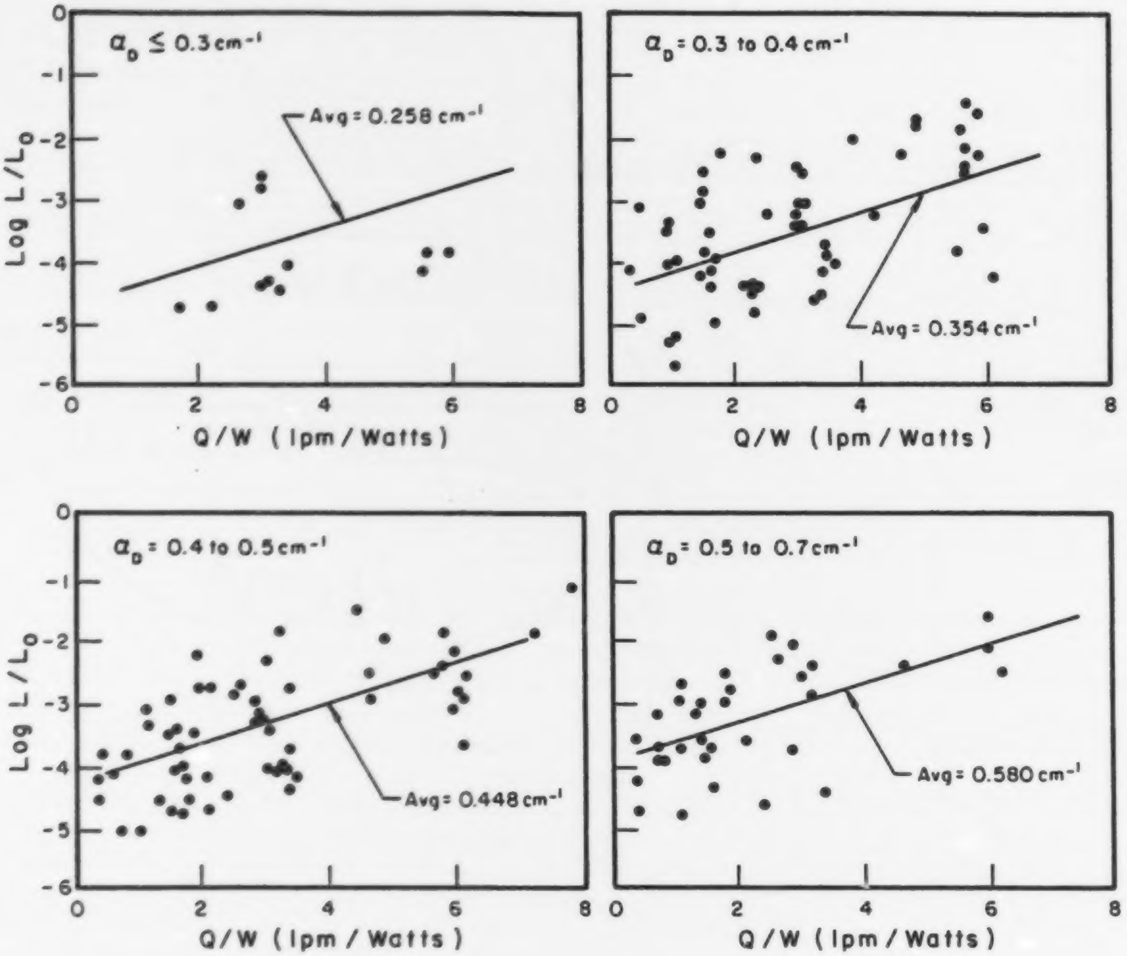
Equation for total coliform, Unit 2:

$$\text{Log } L/L_o = 0.338\ (Q/W) + 2.11\ (\alpha_D) - 5.19$$

Q/W = flow/watt of UV output at 253.7 nm

α_D = direct UV absorbance coefficient, base e, at 253.7 nm

Figure 7-23. Presentation of Unit 2 performance data for total coliform as a function of Q/W and the UV absorbance coefficient.



Equation for fecal coliform, Unit 2:

$$\text{Log } L/L_o = 0.317\ (Q/W) + 2.47\ (\alpha_D) - 5.36$$

Q/W = flow/watt of UV output at 253.7 nm

α_D = direct UV absorbance coefficient, base e, at 253.7 nm

Figure 7-24. Presentation of Unit 2 performance data for fecal coliform as a function of Q/W and the UV absorbance coefficient.

Unit 1 Total Coliform:

$$\text{Log } L/L_o = 0.351(Q/W) + 2.57(\alpha_D) - 5.37 \qquad (7\text{-}21)$$

Unit 1 Fecal Coliform:

$$\text{Log } L/L_o = 0.299(Q/W) + 2.63(\alpha_D) - 5.4 \qquad (7\text{-}22)$$

Unit 2 Total Coliform:

$$\text{Log } L/L_o = 0.338(Q/W) + 2.11(\alpha_D) - 5.19 \qquad (7\text{-}23)$$

Unit 2 Fecal Coliform:

$$\text{Log } L/L_o = 0.317(Q/W) + 2.47(\alpha_D) - 5.36 \qquad (7\text{-}24)$$

The solutions are based on the average α_D for each of the data sets.

For the sake of consistency the data derived for Unit 3 are shown in similar fashion on Figure 7-25. The regression equations appropriate for these presentations are:

Unit 3 Total Coliform:

$$\text{Log } L/L_o = 1.01(Q/W) + 1.59(\alpha_D) - 5.44 \qquad (7\text{-}25)$$

Unit 3 Fecal Coliform:

$$\text{Log } L/L_o = 1.00(Q/W) + 1.84(\alpha_D) - 5.47 \qquad (7\text{-}26)$$

Solutions are shown on the figure for α_D values of 0.3, 0.4, and 0.5 cm^{-1}; The average α_D for the entire data set was 0.352 cm^{-1}.

As stated, the above regressions were presented as an effective way to display the data which had been collected during the term of the project.

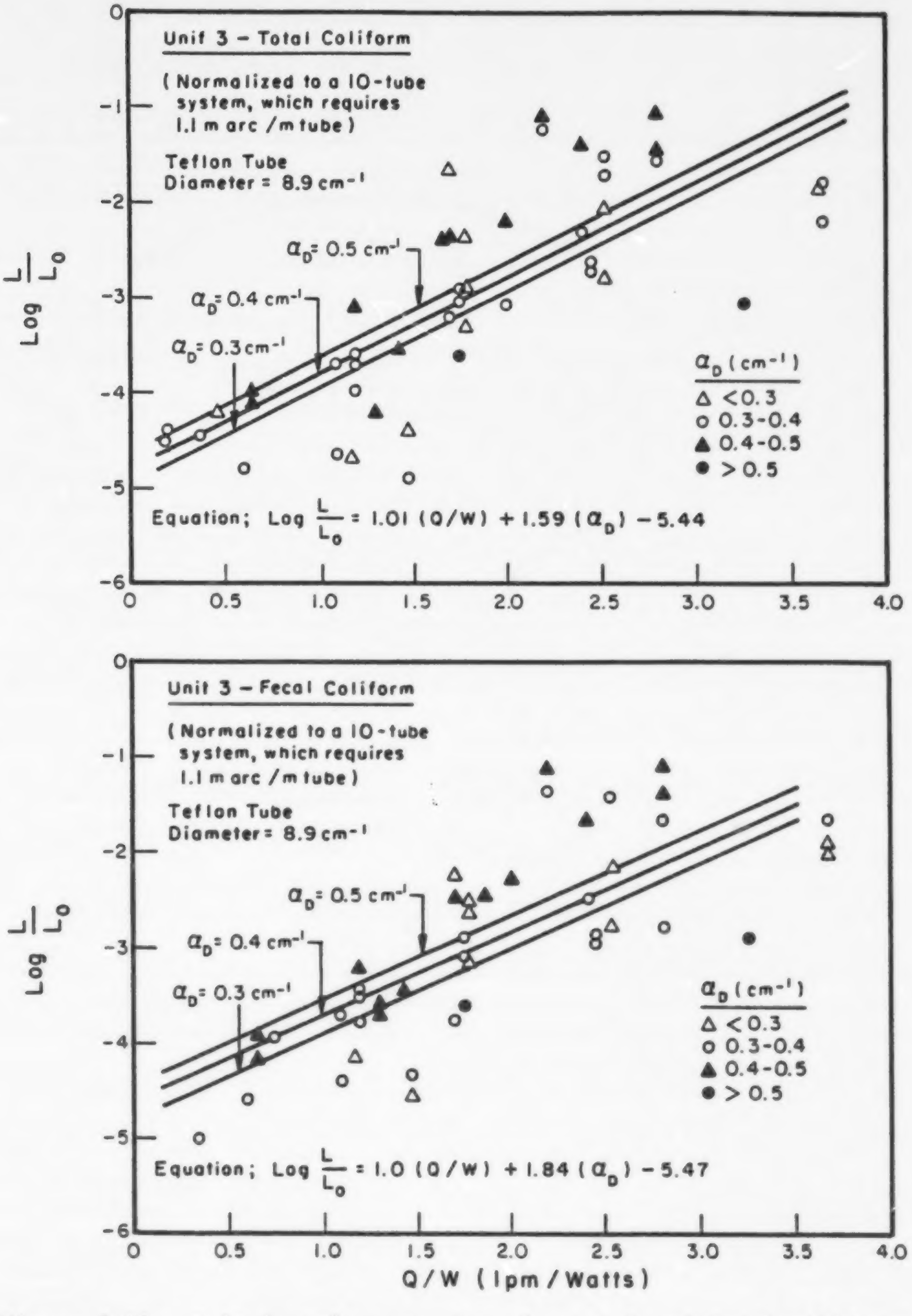


Figure 7-25. Unit 3 performance data for total and fecal coliforms as a function of Q/W and the direct UV absorbance coefficient.

The more effective regressions for the quartz units, however, were those that incorporated the suspended solids concentrations and used the spherical absorbance coefficient rather than the direct absorbance coefficient. These equations can be utilized to size UV systems (of the same configuration) for full-scale applications under various wastewater conditions. The multiple linear regressions are as follows:

Unit 1 Total Coliform:

$$\text{Log } L/L_o = 0.330(Q/W) + 0.033(SS) + 2.40(\alpha_S) - 5.58 \quad (7\text{-}27)$$

Unit 1 Fecal Coliform:

$$\text{Log } L/L_o = 0.315(Q/W) + 0.032(SS) + 2.44(\alpha_S) - 5.59 \quad (7\text{-}28)$$

Unit 2 Total Coliform:

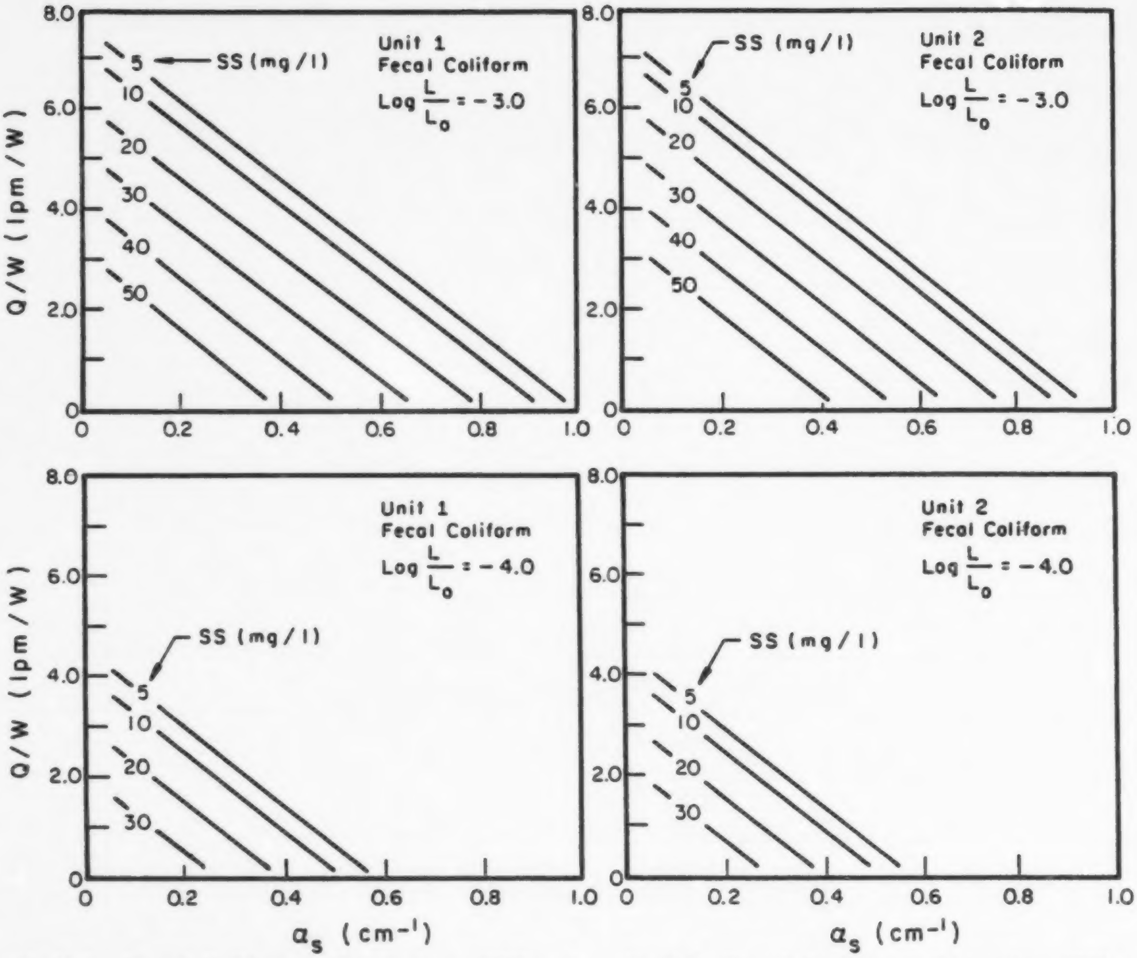
$$\text{Log } L/L_o = 0.345(Q/W) + 0.029(SS) + 1.64(\alpha_S) - 5.26 \quad (7\text{-}29)$$

Unit 2 Fecal Coliform:

$$\text{Log } L/L_o = 0.321(Q/W) + 0.029(SS) + 2.52(\alpha_S) - 5.56 \quad (7\text{-}30)$$

Examples of solutions to these expressions are presented on Figure 7-26. These display the Q/W requirements for either of the quartz units as a function of the UV absorbance coefficient and the suspended solids. The solutions are to achieve Log L/L_o values of -3.0 and -4.0 for fecal coliforms.

Figure 7-27 presents in similar fashion the solutions for Unit 3 to achieve Log L/L_o of -3.0 and -4.0. In this case the regression equation incorporates only the ratio Q/W and the spherical UV absorbance coefficient:



Unit 1, Fecal Coliform – Secondary Effluent

$$\text{Log}\frac{L}{L_o} = 0.315\,(Q/W) + 0.032\,(SS) + 2.44\,(\alpha_s) - 5.59$$

Unit 2, Fecal Coliform – Secondary Eff.

$$\text{Log}\frac{L}{L_o} = 0.321\,(Q/W) + 0.029\,(SS) + 2.52\,(\alpha_s) - 5.56$$

Figure 7-26. Sizing requirements for the quartz units to achieve fecal coliform Log L/L_O of -3 and -4 in a secondary effluent, as a function of suspended solids and absorbance coefficient.

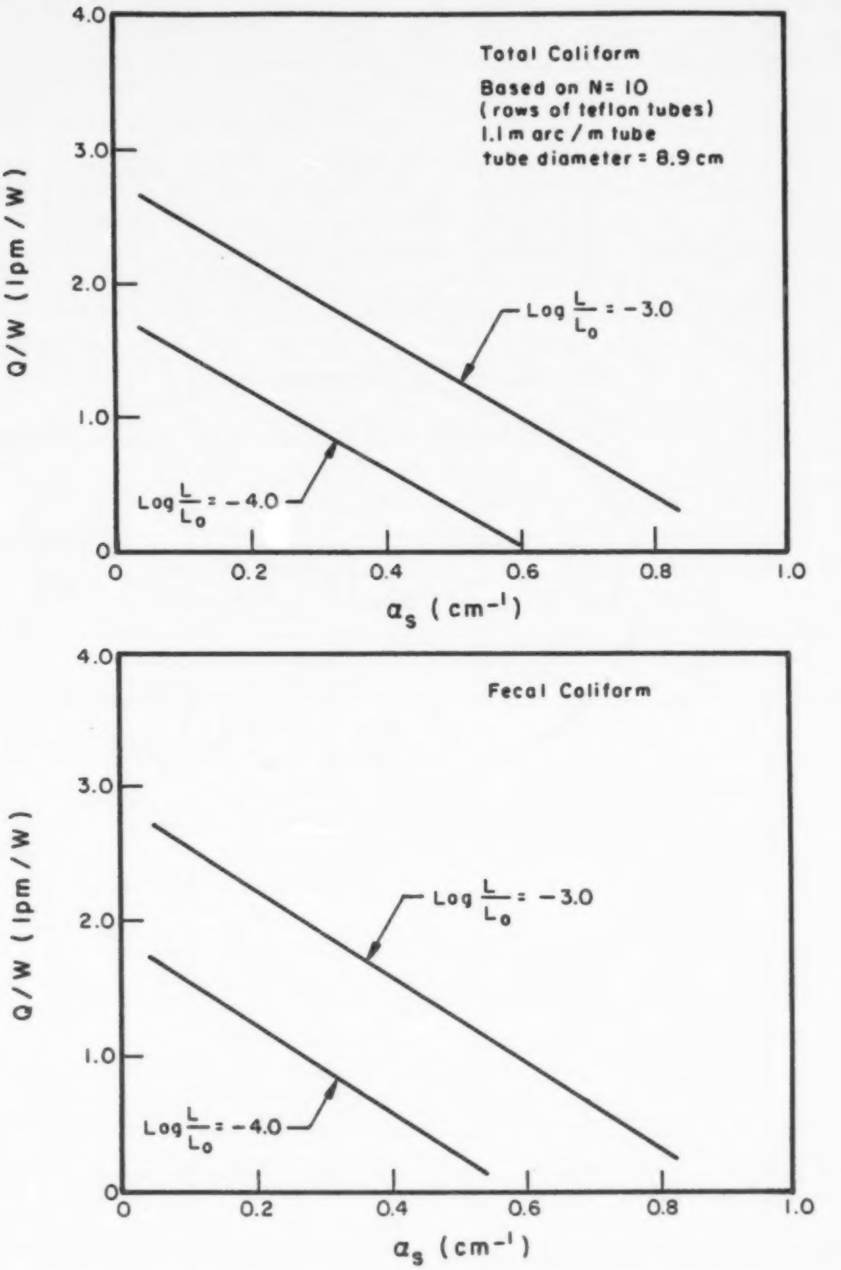


Figure 7-27. Sizing requirements for the teflon system to achieve Log L/L_o of -3 and -4, as a function of the absorbance coefficient.

Unit 3 Total Coliform:

$$\text{Log } L/L_o = 1.02(Q/W) + 2.98(\alpha_S) - 5.83 \qquad (7\text{-}31)$$

Unit 3 Fecal Coliform:

$$\text{Log } L/L_o = 0.99(Q/W) + 3.24(\alpha_S) - 5.86 \qquad (7\text{-}32)$$

Design Example

A simplified design example can now be presented to compare the unit sizes to achieve equivalent performance levels. Consider the following conditions:

Average Daily Flow = 5000 lpm (1.9 mgd)
Peak Daily Flow = 10000 lpm (3.8 mgd)
Effluent Suspended Solids at Peak Flow = 20 mg/l
UV Absorbance Coefficient (α_S) = 0.35 cm^{-1}
Influent Fecal Coliform Density = 200,000 col/100 ml
Required Fecal Coliform Density = 200 col/ 100 ml

Thus, the performance requirement for the UV system is to achieve a Log L/L_o of -3.0 at the peak flow with the SS at 20 mg/l and α_S equal to 0.35 cm^{-1}. From Figures 7-26 and 7-27 (or by direct solution of the appropriate regression equations) the nominal design sizings for the three system configurations are:

Unit 1: Q/W = 3.48 lpm/Watt
Unit 2: Q/W = 3.42 lpm/Watt
Unit 3: Q/W = 1.74 lpm/Watt

Recall that the unit configurations for the quartz systems were symmetrical arrays, with a surface to surface spacing of 5.0 cm for Unit 1 and 1.25 cm for Unit 2. The Q/W ratios for Units 1 and 2 must be further adjusted to account for the losses of UV energy, due both to surface fouling and aging of the lamps. For purposes of this discussion, presume a system loss of 25 percent and the expected output at one-half the lamp life (approximately 75 percent). Thus, the Q/W ratio must be adjusted by:

Q/W required = Q/W (nominal) x 0.75 x 0.75

This yields for each unit,

Unit 1: Q/W = 1.96 lpm/Watt
Unit 2: Q/W = 1.92 lpm/Watt

Similarly, presume a teflon transmittance of 50 percent for Unit 3:

Unit 3: Q/W = 1.74 lpm/Watt x 0.75 x 0.50 = 0.65 lpm/Watt

In order to determine the number of lamps required for each unit, presume using the equivalent of a G64T5L lamp which has a nominal output of 26.7 watts at the 253.7 wavelength. The number of lamps is:

Unit 1:

No. lamps = [10,000 lpm/ (1.96 lpm/Watt)]/26.7 Watts/lamp
= 191 lamps

Unit 2: 195 lamps
Unit 3: 576 lamps

Thus, the two quartz systems are essentially equivalent; each would require approximately 200 lamps to achieve the disinfection goal at the peak flow condition. (This analysis does not address the need for replicate systems, which would be a site specific requirement.) The teflon unit, however, requires a far greater number of lamps to achieve the same performance level.

UV SYSTEM PROCESS PERFORMANCE IN THE TREATMENT OF PRIMARY EFFLUENT

The ability to disinfect primary effluent was investigated to determine if UV would be effective for CSO type wastewaters. At Port Richmond there are portions of the collection system which are combined and the system as a whole is impacted by inflow/infiltration. When the sampling program called for primary effluent evaluations, a portion of the total plant flow would be diverted from the secondary system. The wastewater would then be pumped from the primary bypass channel directly to the UV pilot plant.

A total of 35 acceptable samplings were accomplished; the greater portion of these were conducted in the last two weeks of the field program. Note that in all cases the UV influent and effluent samples were blended before they were set for coliform enumeration. This procedure was discussed in Section 5. As had been shown on Figure 5-2, the blending did not appreciably affect the coliform recoveries for the unexposed samples. Blending the exposed samples, however, was shown to increase the coliform recoveries by as much as one order of magnitude. The coliform inactivation data gathered as part of this project, therefore, is felt to be representative of the actual performance of the UV system; the potential bias caused by occlusion of a significant fraction of the coliforms in the suspended solids has been minimized.

A series of step-wise multiple linear regression analyses were conducted for the primary effluent, as had been done for the secondary effluent data. The resulting equations are summarized in Tables 7-14 and 7-15 for total coliforms (Units 1 and 2) and fecal coliforms (Units 1 and 2) respectively. Note that no acceptable primary effluent information was collected for Unit 3.

As with the secondary effluent regressions, the most significant independent variable was the ratio Q/W. The spherical absorbance coefficient in this case was found to be more effective than the direct absorbance coefficient, when either is coupled with the ratio Q/W. Excellent correlations were achieved when the suspended solids were then

TABLE 7-14. PRIMARY EFFLUENT TOTAL COLIFORM - UNITS 1 AND 2
STEPWISE MULTIPLE LINEAR REGRESSION ANALYSES TO DETERMINE THE CORRELATION
OF THE LOG COLIFORM SURVIVAL RATIO WITH SYSTEM OPERATION AND WASTEWATER QUALITY

Independent Variables[a]	Unit Number	Regression Equation ($\log L/L_o =$)	r^2[g]
Q/W[b]	1	0.45 (Q/W) - 3.26	0.34
	2	0.40 (Q/W) - 3.47	0.46
Q/W and α_s[c]	1	0.454 (Q/W + 2.39 (α_s) - 4.67	0.44
	2	0.426 (Q/W) + 2.3 (α_s) - 4.85	0.61
Q/W and SS[d]	1	0.512 (Q/W) + 0.01 (SS) - 4.23	0.47
	2	0.437 (Q/W) + 0.007 (SS) - 4.15	0.55
Q/W and Turbidity[e]	1	0.45 (Q/W) + 0.0021 (Turb) - 3.30	0.34
	2	0.430 (Q/W) + 0.0042 (Turb - 3.57	0.48
Q/W; α_s; SS	1	0.518 (Q/W) + 0.01 (SS) + 2.4 (α_s) - 5.66	0.58
	2	0.462 (Q/W) + 2.27 (α_s) + 0.0068 (SS) - 5.5	0.70
Q/W; α_s; Turbidity	1	0.454 (Q/W) + 2.71 (α_s) + 0.005 (Turb) - 4.76	0.45
	2	0.427 (Q/W) + 2.44 (α_s) - 0.0019 (Turb) - 4.89	0.62
Q/W; α_s; SS; Turbidity	1	0.518 (Q/W) + 0.011 (SS) + 2.36 (α_s) + 0.0007 (Turb) - 5.66	0.59
	2	0.463 (Q/W) + 2.12 (α_s) + 0.0071 (SS) + 0.0019 (Turb) - 5.49	0.70
Q/W; α_D[f]	1	0.454 (Q/W) + 0.118 (α_D) - 3.37	0.34
	2	0.418 (Q/W) + 0.423 (α_D) - 3.88	0.48
Q/W; α_D; SS	1	0.549 (Q/W) + 0.012 (SS) + 0.70 (α_D) - 5.03	0.50
	2	0.486 (Q/W) + 0.009 (SS) + 0.88 (α_D) - 5.21	0.61

[a] Variables appear in order of importance to the correlations.

[b] Ratio of flow rate to the total UV output of the system (lpm/Watt of 253.7 nm).

[c] α_s is the base e absorbance coefficient at 253.7 nm (cm^{-1}), corrected for scatter.

[d] Suspended solids in mg/l.

[e] Turbidity in NTU.

[f] α_D is the base e absorbance coefficient at 253.7 nm (cm^{-1}) uncorrected for scatter.

[g] The square of the correlation coefficient, r, is an estimate of the variance explained by the regression.

TABLE 7-15. PRIMARY EFFLUENT FECAL COLIFORM - UNITS 1 AND 2 STEPWISE MULTIPLE LINEAR REGRESSION ANALYSES TO DETERMINE THE CORRELATION OF THE LOG COLIFORM SURVIVAL RATIO WITH SYSTEM OPERATION AND WASTEWATER QUALITY

Independent Variables[a]	Unit Number	Regression Equation ($\log L/L_o =$)	r^2[g]
Q/W[b]	1	0.452 (Q/W) - 3.32	0.37
	2	0.404 (Q/W) - 3.57	0.49
Q/W and α_s[c]	1	0.456 (Q/W) + 2.49 (α_s) - 4.79	0.51
	2	0.435 (Q/W) + 2.82 (α_s) - 5.28	0.73
Q/W and SS[d]	1	0.516 (Q/W) + 0.0094 (SS) - 4.23	0.50
	2	0.431 (Q/W) + 0.0048 (SS) - 4.03	0.54
Q/W and Turbidity[e]	1	0.514 (Q/W) + 0.033 (Turb) - 4.32	0.50
	2	0.434 (Q/W) + 0.019 (Turb) - 4.15	0.54
Q/W; α_s; SS	1	0.521 (Q/W) + 2.50 (α_s) + 0.0094 (SS) - 5.72	0.63
	2	0.461 (Q/W) + 2.82 (α_s) + 0.0046 (SS) - 5.73	0.77
Q/W; α_s; Turbidity	1	0.456 (Q/W) + 2.84 (α_s) - 0.0051 (Turb) - 4.89	0.72
	2	0.436 (Q/W) + 3.04 (α_s) - 0.0028 (Turb) = 5.34	0.73
Q/W; α_s; SS; Turbidity	1	0.518 (Q/W) + 2.69 (α_s) - 0.012 (SS) - 0.011 (Turb) - 5.76	0.64
	2	0.45 (Q/W) + 3.3 (α_s) + 0.012 (SS) - 0.028 (turb) - 5.80	0.81
Q/W; α_D[f]	1	0.47 (Q/W) + 0.539 (α_D) - 3.81	0.39
	2	0.437 (Q/W) + 0.774 (α_D) - 4.32	0.55
Q/W; α_D; SS	1	0.568 (Q/W) + 0.012 (SS) + 1.08 (α_D) - 5.43	0.56
	2	0.494 (Q/W) + 1.15 (α_D) + 0.0075 (SS) - 5.41	0.55

[a] Variables appear in order of importance to the correlations.

[b] Ratio of flow rate to the total UV output of the system (lpm/Watt of 253.7 nm).

[c] α_s is the base e absorbance coefficient at 253.7 nm (cm^{-1}), corrected for scatter.

[d] Suspended solids in mg/l.

[e] Turbidity in NTU.

[f] α_D is the base e absorbance coefficient at 253.7 nm (cm^{-1}) uncorrected for scatter.

[g] The square of the correlation coefficient, r, is an estimate of the variance explained by the regression.

added to the regression analyses. Regression of the Log L/L_o against the spherical absorbance coefficient, α_S, the ratio Q/W, and the suspended solids, SS, yielded coefficients of determination (r^2) between 0.58 and 0.77.

The primary effluent performance data are displayed on Figure 7-28. The log survival ratios of total and fecal coliforms are shown as a function of Q/W and the spherical absorbance coefficient, α_S. Data from both Units 1 and 2 are shown. Superimposed on the figures are solutions to the regression equations:

Unit 1, Total Coliform:

$$\text{Log } L/L_o = 0.454(Q/W) + 2.39(\alpha_S) - 4.67 \tag{7-33}$$

Unit 1, Fecal Coliform:

$$\text{Log } L/L_o = 0.456(Q/W) + 2.49(\alpha_S) - 4.79 \tag{7-34}$$

Unit 2, Total Coliform:

$$\text{Log } L/L_o = 0.426(Q/W) + 2.30(\alpha_S) - 4.85 \tag{7-35}$$

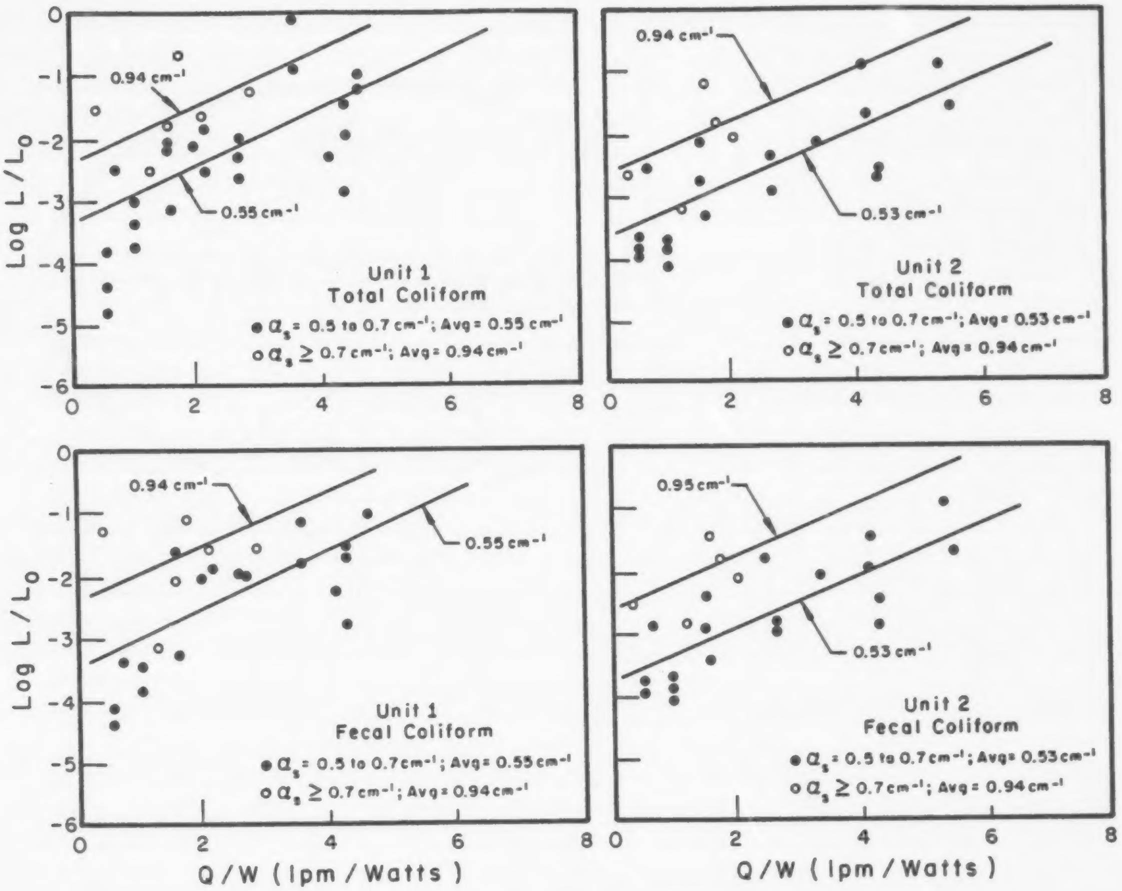
Unit 2, Fecal Coliform:

$$\text{Log } L/L_o = 0.435(Q/W) + 2.82(\alpha_S) - 5.28 \tag{7-36}$$

These regressions are shown with Figure 7-28 as an effective way of displaying the primary effluent data. The more appropriate regression equations for evaluating the performance of the systems, however, are those which include the suspended solids as an independent variable:

Unit 1, Total Coliform:

$$\text{Log } L/L_o = 0.518(Q/W) + 0.01(SS) + 2.4(\alpha_S) - 5.66 \tag{7-37}$$



PRIMARY EFFLUENT

Equations:

Unit 1, total coliform: $\text{Log } L/L_o = 0.454\ (Q/W) + 2.39\ (\alpha_s) - 4.67$
Unit 1, fecal coliform: $\text{Log } L/L_o = 0.456\ (Q/W) + 2.49\ (\alpha_s) - 4.79$
Unit 2, total coliform: $\text{Log } L/L_o = 0.426\ (Q/W) + 2.3\ (\alpha_s) - 4.85$
Unit 2, fecal coliform: $\text{Log } L/L_o = 0.435\ (Q/W) + 2.82\ (\alpha_s) - 5.28$

Q/W = flow/watt of UV output at 253.7 nm
α_s = sphere UV absorbance coefficient, base e, at 253.7 nm

Figure 7-28. Unit 1 and 2 performance data for primary effluent total and fecal coliforms as a function of Q/W and the spherical UV absorbance coefficient.

Unit 1, Fecal Coliform:

$$\text{Log } L/L_o = 0.521(Q/W) + 2.50(\alpha_S) + 0.0094(SS) - 5.72 \qquad (7\text{-}38)$$

Unit 2, Total Coliform:

$$\text{Log } L/L_o = 0.462(Q/W) + 2.27(\alpha_S) + 0.0068(SS) - 5.66 \qquad (7\text{-}39)$$

Unit 2, Fecal Coliform:

$$\text{Log } L/L_o = 0.461(Q/W) + 2.82(\alpha_S) + 0.0046(SS) - 5.73 \qquad (7\text{-}40)$$

Solutions to these equations are presented on Figure 7-29 for either unit to achieve fecal coliform log survival ratios (Log L/L_o) of -3.0 and -4.0. We can now consider a design example to compare the sizing requirements for either unit configuration:

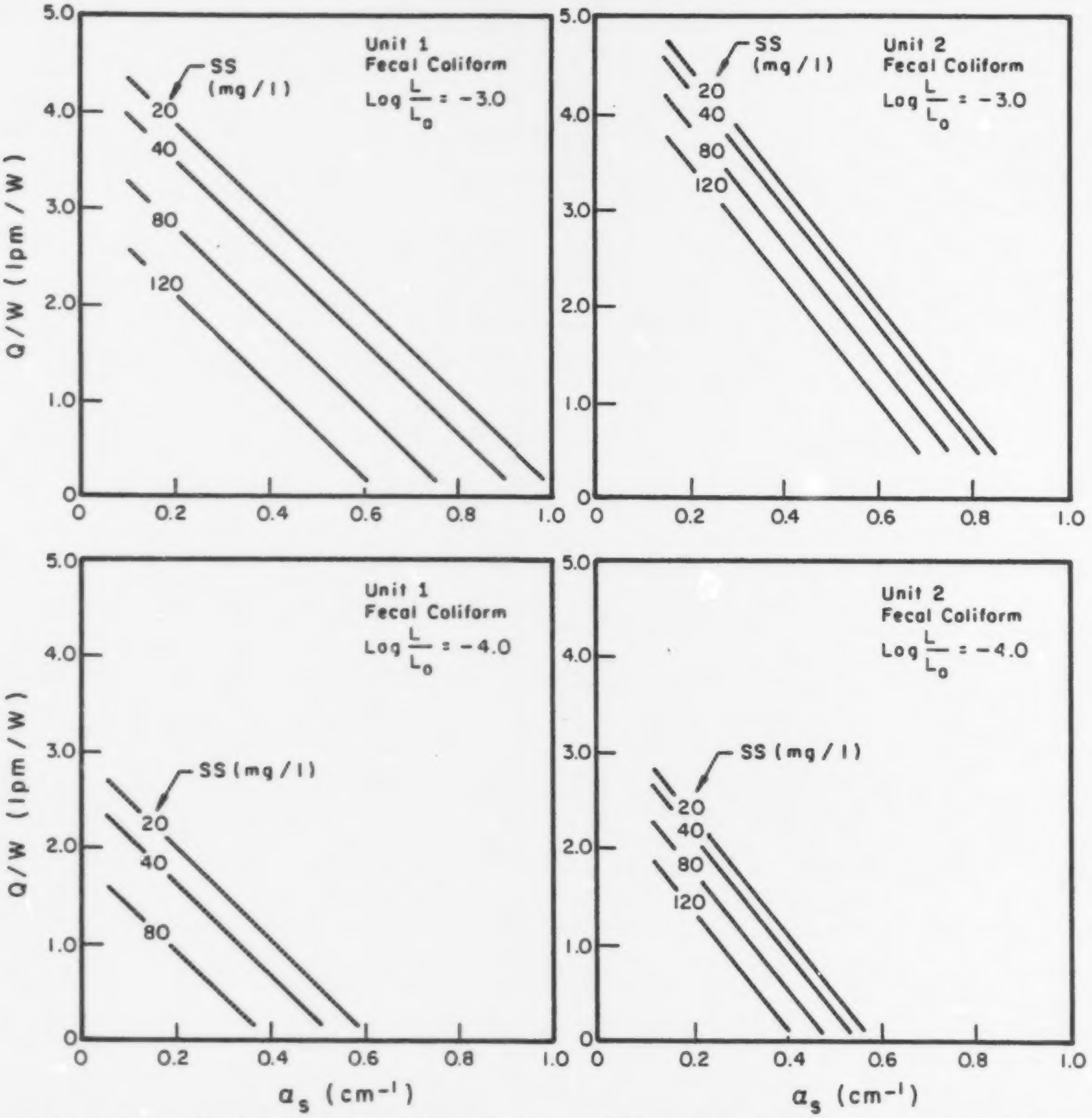
Peak flow = 10,000 lpm
Suspended solids = 80 mg/l
Absorbance coefficient, α_S, = 0.6 cm^{-1}
Required Log L/L_o = -3.0 (Fecal Coliform)

From Figure 7-29 (or by direct solution of Equations 7-38 and 7-40), the required Q/W for either unit is:

Unit 1: 0.9 lpm/Watt
Unit 2: 1.46 lpm/Watt

Again, the ratio must be adjusted to account for the lamp aging and system losses. For this example, assume the lamps are at 75 percent output and there is a 25 percent system loss. The design ratio Q/W then becomes:

Unit 1: $Q/W = (0.75)(0.75)(0.9) = 0.51$ lpm/Watt
Unit 2: $Q/W = (0.75)(0.75)(1.46) = 0.82$ lpm/Watt



Unit 1, Fecal Coliform – Primary Effluent

$$\text{Log}\,\frac{L}{L_o} = 0.521\,(Q/W) + 0.0094\,(SS) + 2.50\,(a_s) - 5.72$$

Unit 2, Fecal Coliform – Primary Eff.

$$\text{Log}\,\frac{L}{L_o} = 0.461\,(Q/W) + 0.0046\,(SS) + 2.82\,(a_s) - 5.73$$

Figure 7-29. Sizing requirements for the quartz units to achieve fecal coliform Log L/L_o of -3 and -4 in a primary effluent, as a function of suspended solids and absorbance coefficient.

Presuming a nominal lamp output of 26.7 watts, the number of lamps required may be determined:

Unit 1: Lamps = [10,000 lpm/ (0.51 lpm/Watt)]/26.7 Watts/lamp
= 734 lamps
Unit 2: Lamps = [10,000 lpm/ (0.82 lpm/Watt)]/26.7 Watts/lamp
= 457 lamps

From this analysis it appears that the closer spacing (Unit 2) is a far more efficient configuration in the treatment of very low grade waters such as the primary effluent. A possible reason may be the apparent laminar conditions suggested at low flow for both units. (The primary effluents were run at relatively low flow.) The effects of stratification would be more likely to show in the widely spaced units, and would be enhanced by the high initial densities found in primary effluents. This may also be an artifact of the small data base. Recall that the units were equivalent in the treatment of secondary effluent.

In all, these empirical relationships show that a level of disinfection can be achieved on primary effluent. A practical limit, as suggested by Figure 7-29, would be a Log L/L_o of -3.0. The lamp requirement is relatively high, approximately 2.5 times that required for an equivalent flow rate of secondary effluent.

PHOTOREACTIVATION

A series of tests were conducted in July and August 1983 to evaluate the impact of photoreactivation. This phenomenon is unique to the mechanism of UV inactivation and involves the ability of the injured organism to enzymatically repair the damage inflicted by the UV radiation. It requires light energy in the visible range, thus subsequent exposure of the UV irradiated sample to sunlight is sufficient to initiate photoreactivation. The test procedure was outlined in Section 5. It involved splitting an exposed sample to three aliquots: the first was immediately set for coliform enumeration; the second was placed in a bottle opaque to visible light; and the third was placed in a bottle transparent to visible light. The two bottles were then held for 60 minutes, at $20^{\circ}C$, exposed to sunlight. The samples would then be set for coliform enumeration; the opaque bottle was the "dark" sample, and the transparent bottle was the "light" sample.

The test results are presented in Table 7-16. A comparison of the results of the "initial" fecal and total coliforms (time zero) with the "dark" total and fecal coliform at 60 minutes showed that there was no significant (five percent) difference between the two data sets. Thus, any differences noted between the "light" coliform densities at 60 minutes and the "initial" coliform densities can be attributed to the repair of the organisms.

These data are plotted on Figure 7-30; both units are combined and the observed Log L/L_o for total and fecal coliform at time 0 and 60 minutes (light) are plotted as a function of the ratio Q/W. Superimposed on these figures are the solutions to the linear regression equations developed for the photoreactivation data:

Fecal Coliforms at t = 0 minutes

$$\text{Log } L/L_o = 0.39\ (Q/W) - 4.22 \qquad (7\text{-}41)$$

Fecal Coliforms at t = 60 minutes (light)

$$\text{Log } L/L_o = 0.46\ (Q/W) - 3.28 \qquad (7\text{-}42)$$

Total Coliforms at t = 0 minutes

$$\text{Log } L/L_o = 0.42\ (Q/W) - 4.32 \qquad (7\text{-}43)$$

Total Coliforms at t = 60 minutes (light)

$$\text{Log } L/L_o = 0.46\ (Q/W) - 3.15 \qquad (7\text{-}44)$$

TABLE 7-16. PHOTOREACTIVATION TEST RESULTS

	Unit 1									Unit 2						
				Log L/L_o - Fecal			Log L/L_o - Total				Log L/L_o - Fecal			Log L/L_o - Total		
Date (1983)	Flow/W (lpm/W)	$^{\alpha}\underline{S}_1$ (cm^{-1})	SS (mg/l)	Initial	Dark	Light	Initial	Dark	Light	Flow/W (lpm/W)	Initial	Dark	Light	Initial	Dark	Light
7-26		0.589	26.8							1.75	-	-	-	-3.90	-3.61	-
26		0.628	23.6							0.34	-4.34	-4.41	-3.16	-4.37	-4.35	-2.92
26		0.566	6.4							4.96	-2.04	-2.02	-	-2.17	-	-
27	1.63	0.541	24.8	-3.64	-3.74	-2.40	-3.55	-3.69	-2.07	1.75	-4.09	-3.85	-2.61	-4.15	-3.83	-2.60
27	0.32	0.570	30.0	-3.41	-3.89	-3.12	-3.48	-4.07	-2.96	0.34	-3.98	-3.40	-3.57	-3.86	-3.84	-3.59
27	5.23	0.575	28.8	-2.73	-2.15	-0.97	-2.68	-2.14	-0.98	5.60	-1.77	-1.77	-0.60	-1.85	-1.79	-0.65
8-02	4.62	0.435	8.8	-2.0	-1.85	-1.31	-2.04	-1.71	-1.14	4.96	-1.78	-1.39	-0.60	-1.64	-1.22	-0.62
03	3.06	0.462	4.0	-2.91	-3.28	-2.04	-2.87	-3.13	-2.0	3.28	-2.56	-2.86	-0.73	-2.55	-2.24	-0.87
04	1.53	0.510	12.0	-3.81	-3.66	-2.69	-3.57	-3.76	-2.25	1.64	-3.42	-	-2.00	-3.84	-3.64	-2.08
8-08	4.45	0.297	2.0	-2.55	-2.93	-1.49	-2.45	-2.40	-1.12							
08	3.45	0.276	3.6	-3.26	-2.87	-1.69	-2.74	-2.52	-1.31							
08	2.10	0.290	3.6	-4.03	-3.83	-2.48	-3.75	-3.79	-2.38							
8-09	3.45	0.361	7.4	-	-3.18	-2.23	-3.47	-3.44	-1.94							
09	2.10	0.354	2.2	-	-3.74	-2.70	-4.21	-3.89	-2.73							
09	4.45	0.345	3.8	-3.12	-2.98	-1.23	-2.86	-2.63	-1.02							
8-11	4.45	0.398	8.8	-2.84	-2.75	-1.82	-2.56	-2.33	-1.66							
11	3.45	0.432	9.2	-2.41	-2.40	-1.36	-2.52	-2.36	-1.37							
11	2.10	0.446	10.4	-3.10	-3.11	-1.57	-3.09	-3.11	-1.69							

Note:

Initial = t = 0
Dark = t = 60 minutes; dark bottle
Light = t = 60 minutes; light bottle

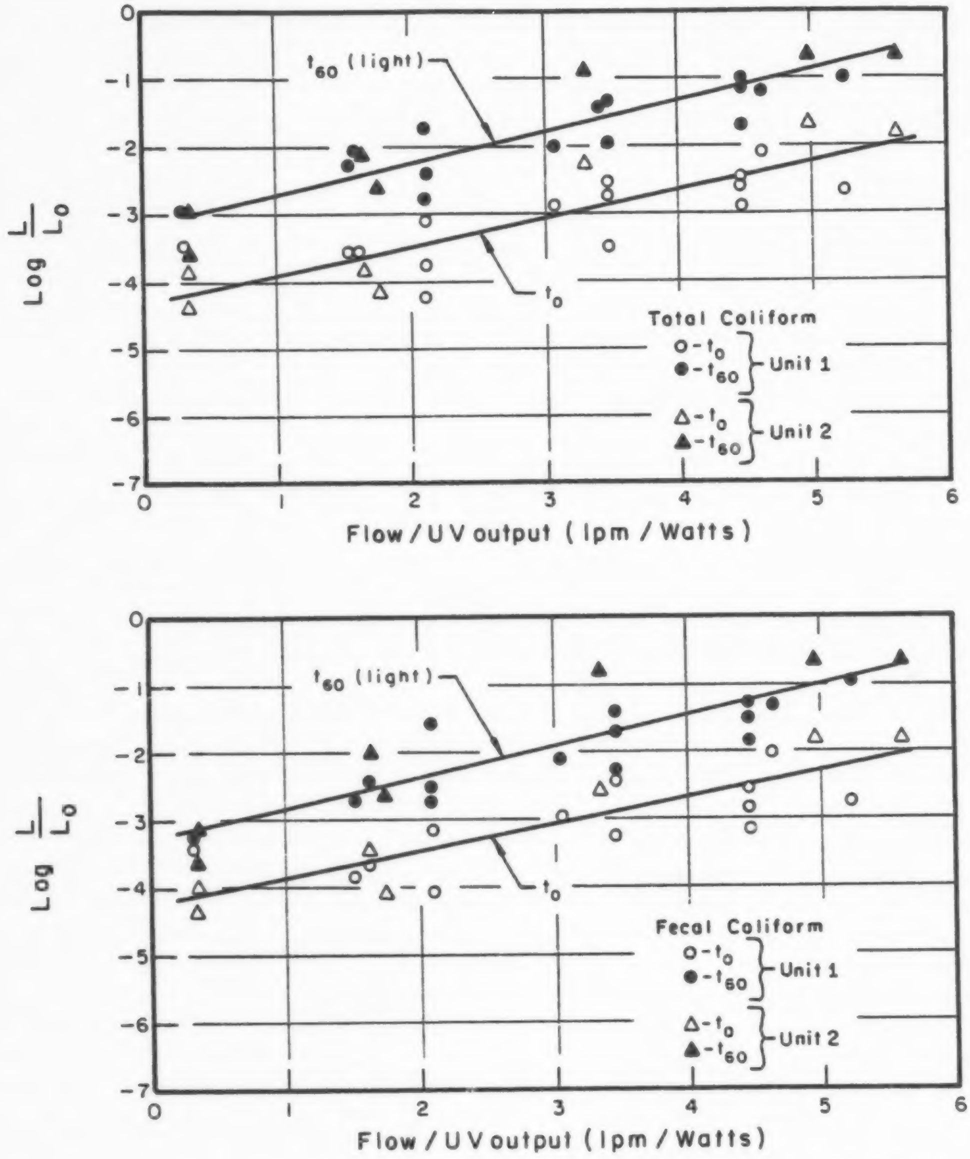


Figure 7-30. Photoreactivation effects for total and fecal coliforms.

The suspended solids averaged 11.8 mg/l during this period; the average spherical absorbance coefficient was 0.448 cm^{-1}. As shown on Figure 7-30, the photoreactivation mechanism causes an increase of approximately 1.3 logs in either the total or fecal coliforms. The increase is relatively constant, regardless of the applied dose, as represented by the ratio Q/W. The data, as presented, also indicated that there is approximately a three-fold increase in the system sizing requirement to achieve an equivalent performance, if photoreactivation were to be taken into account.

DOSE--RESPONSE ANALYSIS

Bench-scale batch tests were conducted to develop a dose-response relationship for fecal coliforms sampled directly from the Port Richmond secondary effluent. The procedures have been outlined in Section 5. The test involved exposing a sample to a collimated beam of UV light of known intensity for a number of time intervals. The dose would then be the intensity (averaged through the depth of the liquid) times the exposure time:

$$\text{Dose } (\mu\text{Watt-sec/cm}^2) = \text{I avg } (\mu\text{Watts/cm}^2) \times t \text{ (seconds)}$$

where:

$$\text{I avg} = I_o \left[\frac{1 - \exp(\alpha_D d)}{\alpha_D d}\right]$$

I_o is the measured intensity at the surface of the liquid, d is the depth of the liquid (cm), and α_D is the direct absorbance coefficient (cm^{-1}). The residual fecal coliform would be measured at each dose level.

A number of the samples were also centrifuged (low speed for approximately one minute) to determine the effects of suspended solids on the subsequent dose-response tests.

The results of the batch tests are summarized on Table 7-17. These were then reduced to Dose (I_{avg} x t) and Response (log L/L_o) and plotted on Figure 7-31. The figure is typical of the dose-response curves normally developed; the relationship is linear for the initial portion of the curve and then tails out with increasing dose levels. This tailing effect is generally attributed to the shadowing and/or occlusion effects of the suspended solids contained in the samples. The centrifuged data tended to retain its linearity for a far greater range of dose, supporting the premise of the solids effects.

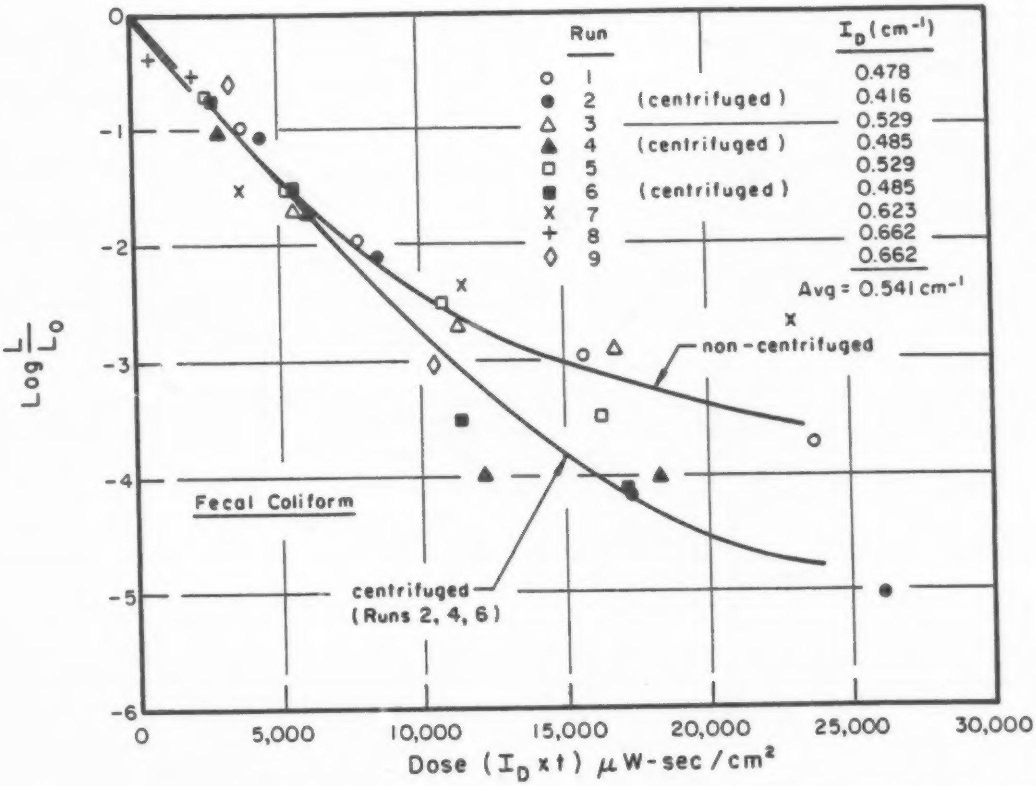


Figure 7-31. Dose-response curve for fecal coliform (intensity is based on direct UV absorbance coefficient).

TABLE 7-17. SUMMARY OF DOSE-RESPONSE BIOASSAY TEST DATA

Run Number	1	2	3	4	5	6	7	8	9
Date	4-01-82	4-01-82	5-10-83	5-10-83	5-10-83	5-10-83	8-25-83	8-25-83	8-25-83
Sample Preparation[a]	-	Centrif.	-	Centrif.	-	Centrif.	-	-	-
α-Direct (cm^{-1}) - D	0.478	0.416	0.529	0.485	0.529	0.485	0.623	0.662	0.662
α-Sphere (cm^{-1}) - S	0.423	0.340	0.462	0.430	0.462	0.430	0.534	0.587	0.587
I_o (surface) ($\mu W/cm^2$)	155	155	115	113	109	109	490	100	475
Liquid Depth (cm)	4.3	4.3	4	4	4	4	6	6	6
I_{avg} ($\mu W/cm^2$) - S[b]	65.7	72.2	46.9	50.8	45.3	48.1	128	24.7	117
- D	71.4	81.4	51.5	54.9	49.7	52.0	147	27.5	131
L_o at t_o (col/100 ml)	542,000	410,000	480,000	290,000	310,000	210,000	295,000	295,000	295,000
L_o at t_N (col/100 ml)	460,000	470,000	280,000	350,000	500,000	270,000	130,000	130,000	130,000
Avg L_o (col/100 ml)	500,000	439,000	366,000	319,000	394,000	238,000	196,000	196,000	196,000
L_o (col/100 ml) at									
t = 30 sec.							5,670		14,300
60 sec.	53,000	36,000		31,000	77,000	48,000		73,000	
90 sec.							900		160
120 sec.	5,700	3,100	6,900	5,900	12,000	8,100		16,700	
180 sec.							400		
240 sec.	552	30	730	33	1,300	65			
360 sec.	100	4	460	31	130	19			

[a] Centrifuged

[b] $I_{avg} = I_o \left(\frac{1-e^{-\alpha d}}{\alpha d}\right)$; where d = depth.

The dose-response data presented on Figure 7-31 were then utilized to estimate the apparent "dose" achieved for each of the three units. Equations 7-22, 7-24, and 7-26 were solved at an $\alpha_D = 0.54$ cm^{-1} (average α_D for the dose-response test) to yield the Q/W required to achieve Log L/L_o (fecal coliform) values of -1, -2, -3, and -3.5. From Figure 7-31, these log survival ratios are equivalent to doses of 3000, 8000, 15000, and 22000 µWatt-sec/cm^2. The Q/W required for each unit to achieve the equivalent dose is plotted on Figure 7-32, yielding a dose-sizing relationship.

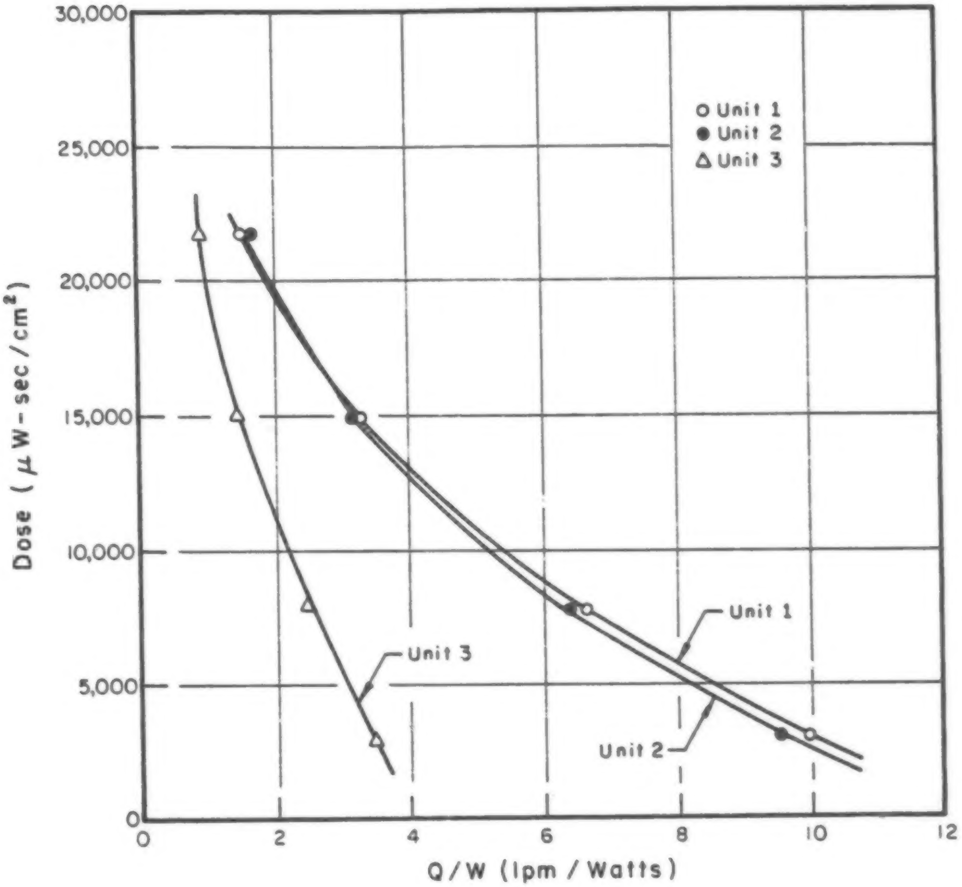


Figure 7-32. Estimated dose for each of 3 units as a function of Q/W (based on batch dose-response tests).

The equivalency of the two quartz systems is evident from Figure 7-32. The teflon unit is shown to be very different, however. This is somewhat anomalous; the Q/W should be fairly uniform among unit configurations to yield equivalent "doses". This is obviously not the case with Figure 7-32. This may be related to the estimate of transmittance for the teflon unit; the Q/W estimates for Unit 3 assumed the teflon transmittance to be between 30 and 75 percent. If this is cut in half, the Q/W-Dose curve would be closer to those shown for Units 1 and 2.

SECTION 8

APPLICATION OF THE PROPOSED DISINFECTION MODEL

INTRODUCTION

A framework was proposed in Section 6 which would mathematically describe the process performance of a UV disinfection system. The model incorporates the critical elements of a system design: the hydraulic characteristics, the intensity, and the quality of the wastewater to be disinfected. The model can be calibrated, given the appropriate set of data for a particular application. The calibrated model can then be utilized to test the sensitivity of performance to specific design parameters, to optimize the design of a particular system, and to monitor and refine the operations of an existing system.

The data collected as part of the Port Richmond project were utilized in such a manner. The following discussions present the data and methods used to calibrate the proposed model and its subsequent application to the Port Richmond project.

PROPOSED UV DISINFECTION MODEL

It is appropriate at this point to reiterate the proposed model, and to relate the model parameters directly to the three units which were operated at Port Richmond. The subsequent discussions will then detail how the data were utilized to calibrate and operate the model. Recall from Section 6, Equation 6-12:

$$L = L_o \exp \left[\frac{ux}{2E} \left\{1 - \left(1 + \frac{4KE}{u^2}\right)^{1/2} \right\}\right] + L_{particulate} \qquad (8\text{-}1)$$

where:

L = the bacterial density remaining after exposure to UV. This will have the unit colonies/100 ml for the Port Richmond application.

L_o = the initial bacterial density, measured immediately before entry into the UV reactor. Units are colonies/100ml.

x = the distance traveled by an element of water while under direct exposure to UV light. This is in centimeters. The value of x for the two quartz systems (Units 1 and 2) is the dimension of the lamp battery in the direction of flow. One-half the spacing between quartz surfaces would be added at the inlet and outlet to account for the boundaries in this x dimension. Thus, for Units 1 and 2, when all three banks were operating, the value of x was 74.4 and 40.6 cm, respectively. With two banks of lamps in operation, the value of x was 45.2 and 26.4 cm, respectively. The x dimension for the teflon unit was simply the length of the teflon tubes under exposure to the lamps. This was 300 cm in all cases.

u = the velocity of the wastewater as it travels through the UV reactor in cm/sec. This is calculated as:

$$u = x/(V_v/Q)$$

The parameter x has been defined. The parameter Q is the flow rate in liters/second (l/sec). V_v is the reactor void volume. For the quartz units the void volume is the total lamp battery volume minus the volume displaced by the quartz sleeves. The value of V_v for Units 1 and 2 was 345 and 75 liters, respectively, with all banks in operation. With two banks in operation, the values of V_v were 210 and 50.2 liters, respectively. The V_v for Unit 3 was the volume of the teflon tube. This was 8.5 liters for the 6 cm diameter tube and 18.7 liters for the 8.9 cm diameter tube.

E = the dispersion coefficient in cm^2/second. These were determined directly for the two quartz units. The estimates of E are discussed later.

K = the rate coefficient for inactivation of fecal or total coliforms (sec^{-1}). The value of K was determined as a function of the estimated intensity for the UV systems. The intensity for a given sampling for each unit was approximated by the point source summation calculation method, utilizing the computer program TULIP. The application of this calculation technique is discussed subsequently, as is the estimate of the K rate.

$L_{particulate}$ = the bacterial density associated with the particulates in the wastewater. These coliforms are affected minimally by the UV irradiation, effectively becoming the base residual density determining the performance of a given system. At Port Richmond the particulates were related to the direct measure of turbidity and suspended solids.

Thus, aside from knowing the physical dimensions of the system (x,V_v), and the system loading conditions (Q and L_o), the model requires knowledge of the hydraulics of the system (E), the sensitivity of the coliform to UV (K, which in turn is to be defined as a function of the calculated intensity), and the characteristics of the wastewater (coliform occlusion in the particulates, and, as will be discussed with regard to the intensity, the UV energy absorption properties of the fluid).

HYDRAULIC CHARACTERISTICS

As had been discussed in Section 6, it is important that the system design approximate plug flow conditions. This allows each plug of fluid passing through the system to be exposed for the maximum time, i.e., its theoretical detention time. Ideal plug flow is generally not practicably achievable; it then becomes important to characterize the retention (exposure) time distribution for a given system. The proposed model utilizes a one dimensional advective-dispersive expression which presumes that both flow and dispersion are unidirectional. The dispersion, or spread of the time distribution curve (see Figure 6-1), is characterized by the dispersion coefficient, E (cm^2/second). As E approaches infinity, the system approaches complete mix; as E approaches zero the system is approaching ideal plug flow.

Direct measurements were made on the two quartz systems to develop the time distribution curve and to subsequently approximate the dispersion coefficient for either system. The results of these tests and their analysis are presented in Section 7. The values of E assigned to the two quartz systems were 1.5 cm^2/sec for Unit 1 and 15 cm^2/sec for Unit 2.

An important assumption is inherent to the use of the dispersion coefficient in the disinfection model. It presumes that turbulent flow conditions exist under normal operating conditions. Conversely, laminar conditions are to be avoided. The reasoning behind this, as will be shown by the intensity calculations, is that there are non-uniform intensity fields within a system; the intensity will be the highest at points closest to the lamps and lower at points away from the lamps. By maintaining turbulence, a microorganism is given an equal probability of seeing all intensity levels within the unit. If a laminar condition exists, there is the chance that the organism may be carried in a stratified flow condition and be exposed to the lower intensity levels only. The results presented in Section 7 suggest that the turbulent flow condition may not have been met by the two quartz units at the lower flow levels.

The teflon unit (Unit 3) was not tested directly to determine the dispersion coefficient. Discussions are presented in Section 7 to support assigning a low E to the unit; for purposes of this analysis, an E of 0.5 cm^2/sec is assumed. Calculations are also presented in Section 7 to show that turbulent conditions are likely under the entire operating flow range for the unit.

UV INTENSITY

The reader is again referred to the discussions in Section 6, which presents the framework by which the average intensity is computed for each of the three units for the given wastewater and operating conditions. The computer program, TULIP, utilizes the point source summation technique to calculate the intensity at any point within the lamp battery. The intensity model makes two assumptions: (1) that the lamp arc can be treated as a series of point sources which emit radiation in all directions, and (2) that each receiver (i.e., microorganism) is infinitely small and is spherical, such that any light striking the particle is perpendicular to the particle surface.

The program requires that the lamp battery configuration be set up in a three dimensional coordinate system (refer to Figure 6-4); although symmetry is not required, it is necessary for the lamps to be parallel to one another. The lamp battery is then sliced to yield a cross-section which is perpendicular to the lamps. This cross-section is then divided into a grid of equal area boxes, with a designated receiver location at the center of each of these grid boxes. An example is shown on Figure 6-6.

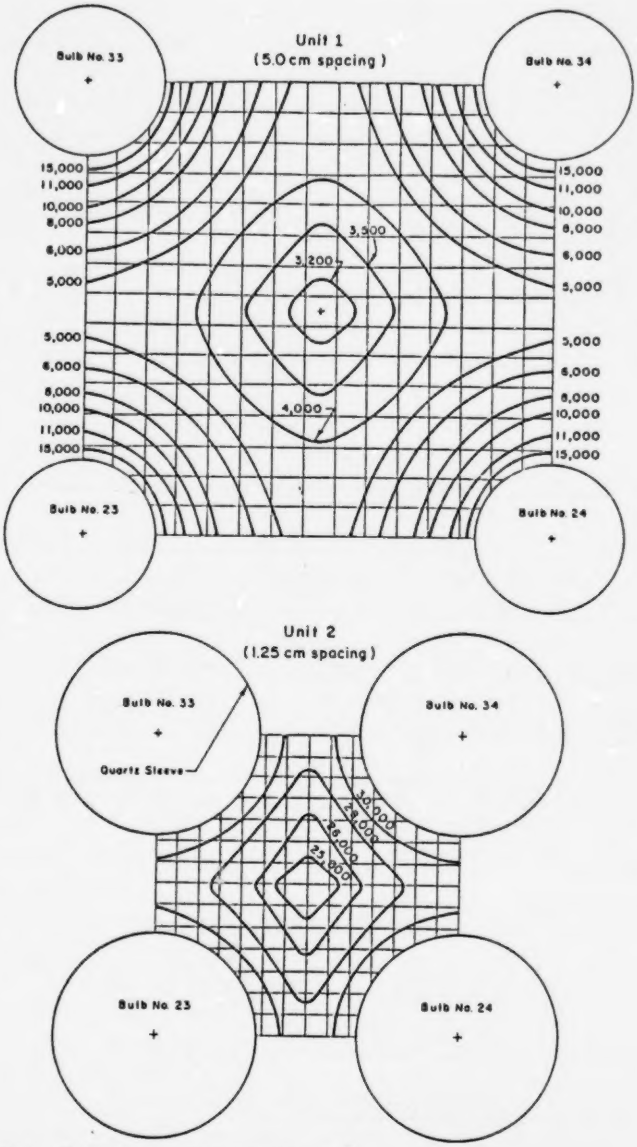
TULIP then computes the intensity at each receiver location in a designated cross-sectional grid. It takes into account the geometry of the system, the characteristics of the lamps and enclosures (e.g., quartz or teflon), and the given UV absorptive properties of the liquid. In the case of mercury arc lamps (which are used in nearly all UV system designs) the model also presumes that any energy at the 253.7 nm wavelength which enters a lamp from a neighboring lamp will be completely absorbed by that lamp. The intensity at a given receiver location is calculated as the sum of intensities from all bulb subelements (i.e., the point sources along the arc of each lamp) in the entire lamp battery. Once the intensities are computed for each of the receivers in a grid, the average is taken and is presumed to be the average intensity within that grid. It is in this manner that the average intensity is computed for a given system configuration.

Intensity Calculations for the Quartz Systems (Units 1 and 2)

A three-dimensional coordinate system was set up for Units 1 and 2. The lamp length was along the z axis, with the terminus of the lamp at z = 0.0. The x and y coordinates of each lamp were determined from the spacing of the system and the diameter of the quartz sleeves. Recall that the spacing (between outer quartz surfaces) was 1.25 and 5.0 cm for Units 1 and 2, respectively. The outer diameter of the quartz sleeve was 2.3 cm in all cases. The UV source (i.e., the lamp arc) was assumed to be at the center of the quartz sleeve. The boundaries on the inlet and outlet planes of the lamp batteries were assumed to be one half the spacing distance for that particular system.

The grids were set for each unit. A grid of 130 receivers in the area between 4 bulbs was used for Unit 2; 205 receivers were set in a 4 bulb area for Unit 1. The number of receivers established for a given system will affect the accuracy of the estimated average intensity; increasing the number of receivers will improve the estimates but will also increase the computational time. Sensitivity runs established that increasing the number of receivers beyond the 205 or 130 for Units 1 and 2, respectively, did little to improve the average intensity estimate. By symmetry it can also be established that only one octant need be computed to determine the overall grid intensities (when there are no boundary effects).

Figure 8-1 presents examples of solutions for a four lamp grid in Units 1 and 2 at a wastewater absorbance coefficient of 0.3 cm^{-1}. Isointensity lines are shown indicating the variation of the intensity field within the UV reactor. Note that although the solution shows only four lamps, the calculated intensities account for all lamps in the system which impact each receiver location. Several runs were made to evaluate how far this influence extends from a given receiver location under differing UV absorbance characteristics. That is, for a given receiver, what is the distance beyond which there is little influence from a point source. This distance is referred to as the R_{max} (cm) and is a function of the absorbance of the water and the spacing configuration of the lamp battery.


Unit 1
(5.0 cm spacing)
Bulb No. 33
Bulb No. 34
Bulb No. 23
Bulb No. 24
15,000
11,000
10,000
8,000
6,000
5,000
3,500
3,200
4,000
Unit 2
(1.25 cm spacing)
Bulb No. 33
Bulb No. 34
Bulb No. 23
Bulb No. 24
Quartz Sleeve
30,000
28,000
26,000
23,000

Note: Intensities are in μ Watts / cm^2

Figure 8-1. Examples of intensity calculations for Units 1 and 2 at an absorbance coefficient of $0.3\ \text{cm}^{1}$ (not to scale).

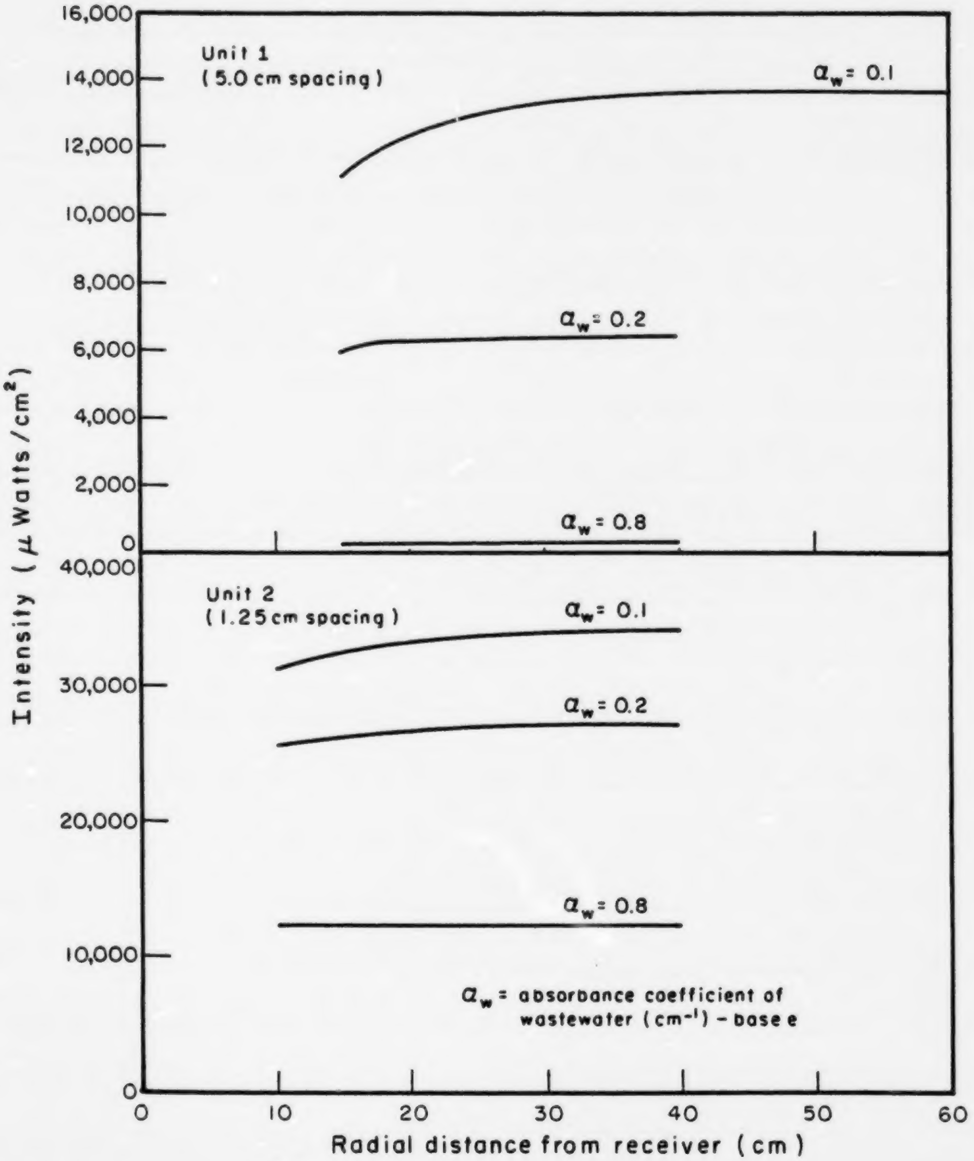


Figure 8-2. Analysis to evaluate effective distance about a receiver.

Figure 8-2 presents the relationship of the R_{max} with the computed intensity at absorbance coefficients of 0.1, 0.2, and 0.8 cm^{-1} for both quartz units. As would be expected, there is an increasing radius of influence with increasing quality (lower absorbance coefficient); the figure also shows that at absorbance coefficients greater than 0.2 cm^{-1} (a lower value for tertiary effluents), there is little influence beyond 10 cm. This R_{max} was incorporated into the TULIP program to reduce computation time.

The program was also run to characterize the boundary conditions in the reactor at the ends of the lamps, presuming no reflectance off the endwalls of the reactor shell. A receiver in a fixed x-y position was moved along the length of the lamp battery from z = 0 to z = 73 cm (the internal dimension of the quartz units). A solution for Unit 1 at an absorbance coefficient of 0.3 cm^{-1} is presented on Figure 8-3.

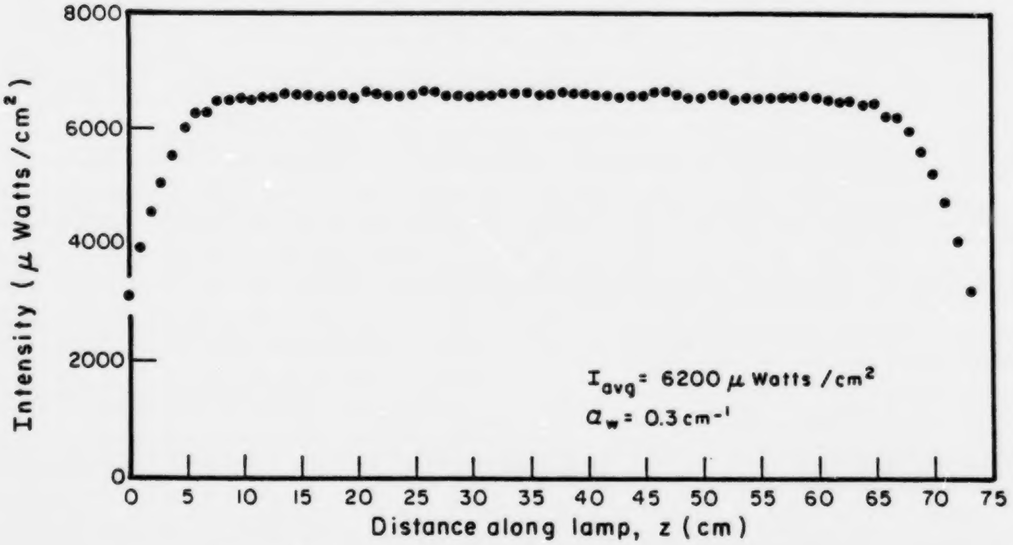


Figure 8-3. Calculation of intensity along the length of a lamp.

The intensity is shown to begin declining at approximately 7 cm before each wall. The intensity at the wall was found always to be approximately one half the intensity averaged across the entire lamp length; this also simplified the computational model since only the receivers at z = 0 had to be evaluated and the average across the z-axis could then be approximated by multiplying the intensity at z = 0 by two.

With regard to the two quartz units it was necessary to determine the intensities in only one quarter of the system, since the units were symmetrical. It was assumed that the average intensity in that quarter would apply to the remainder of the system. Further refinements to the computational model showed that only selected grids within the quadrant needed to be evaluated to effectively represent the entire quadrant.

Figure 8-4 is the final product of the TULIP intensity analysis. It presents the average computed intensity (at the 253.7 nm wavelength) for each of the quartz units as a function of the UV absorbance coefficient.

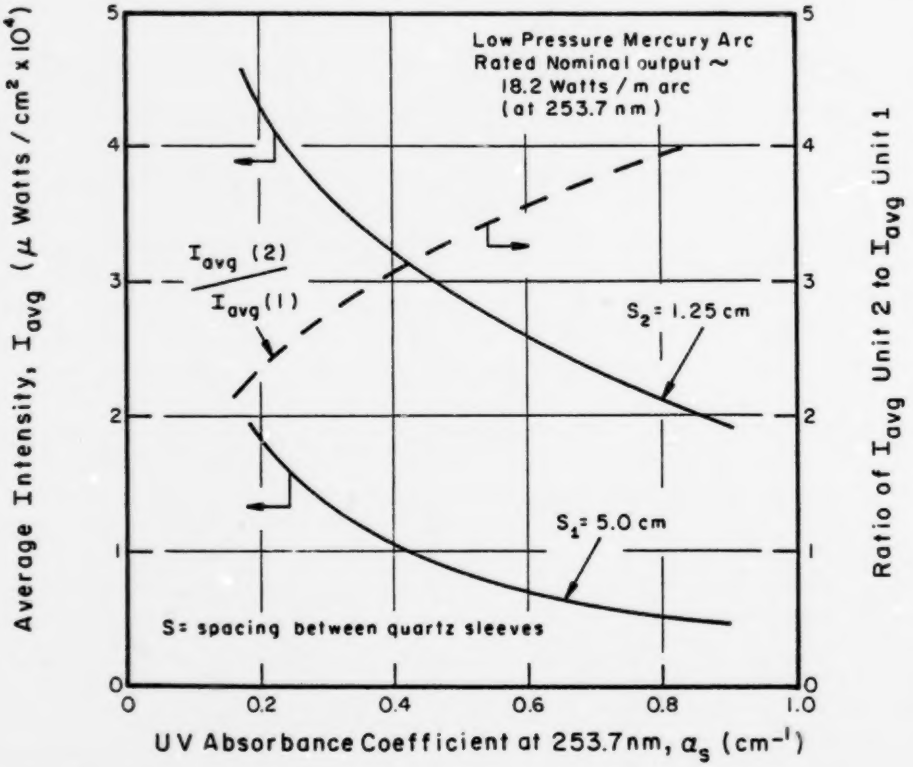


Figure 8-4. Solutions of intensity model for Units 1 and 2 as a function of the UV absorbance coefficient.

As shown, the intensity decreases with increasing absorbance by the liquid. Also, as expected, the intensity in the closely spaced system is far higher than that of the widely spaced system. A second relationship is also shown on Figure 8-4: the ratio of the intensity in Unit 2 (1.25 cm spacing) to the intensity in Unit 1 (5.0 cm spacing) as a function of the absorbance coefficient. This is presented to show the effects of "shadowing," whereby a lamp will absorb any UV energy reaching it. Thus, if the lamps are spaced closely, as with Unit 2, and the wastewater is relatively clean with an absorbance coefficient of 0.2 cm^{-1}, then much of the energy emitted is being absorbed by the neighboring lamps. From Figure 8-4, the ratio I_2/I_1 is approximately 2.35. As the absorbance coefficient increases there is less light reaching the neighboring lamps and the energy is being utilized more efficiently. This is demonstrated by the increasing ratio I_2/I_1, which is 3.0 at an α of 0.3 cm^{-1}, and increases to 4.1 at an α of 0.8 cm^{-1}.

There is a very important note to Figure 8-4. The intensity is calculated at the nominal output of a low pressure mercury arc lamp. This is approximately 18.2 Watts/meter of arc. The power is the rated output of the lamp at the 253.7 nm wavelength. Thus, the intensity must be adjusted to the actual output estimated for a given operating condition. This is done by multiplying the I_{avg} from Figure 8-4 by the ratio of the actual UV output to the nominal UV output ($P_{actual}/P_{nominal}$). This was accomplished for Port Richmond Units 1 and 2 by the relationships presented on Figure 7-19, which estimates the P_{actual} at any given time in the study. It accounts for all losses of UV energy up to the point of entry into the liquid; Figure 8-4 then accounts for the losses in the liquid itself (absorbance coefficient).

With the information presented on Figures 7-19 and 8-4, it was then possible to estimate the average intensity in either reactor on any given sampling in which the absorbance coefficient was determined. These intensities are displayed chronologically as monthly averages for Units 1 and 2 on Figure 8-5. The computed intensities are shown on the basis of the UV absorbance coefficient measured by both the direct and spherical methods. The calculation technique for intensity does not differentiate

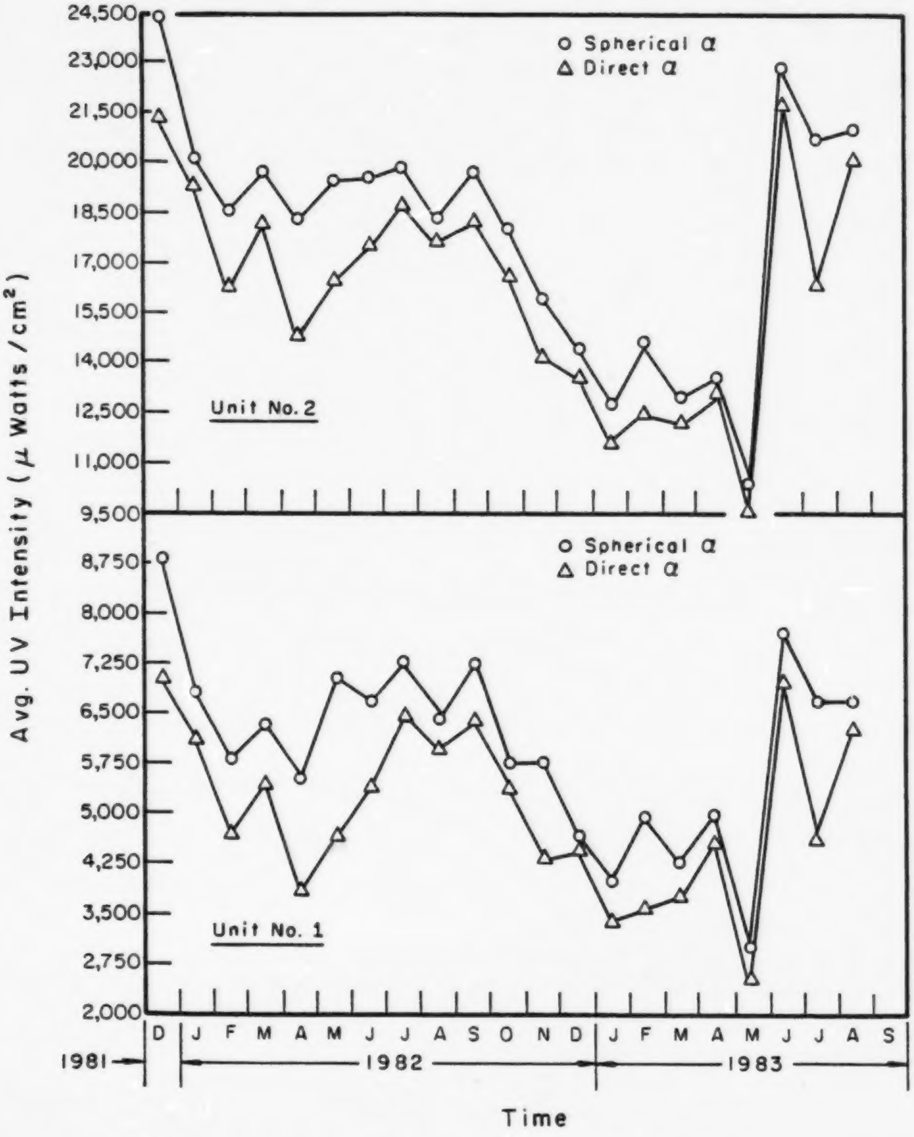


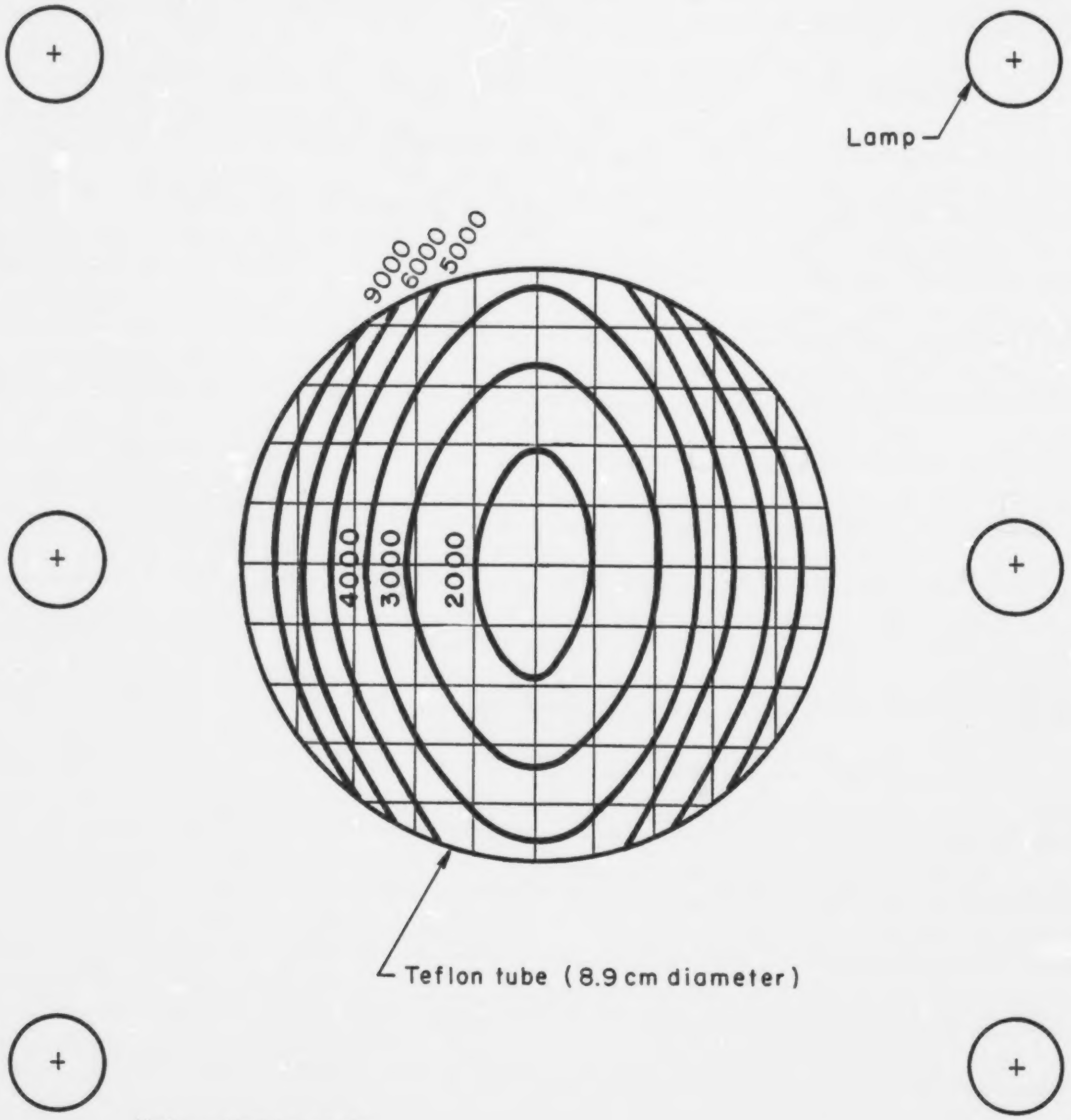
Figure 8-5. Chronological record of monthly averages of the calculated intensities for Units 1 and 2.

between measurement methods for absorbance, but inherently presumes that it is a true absorbance value. From the discussions presented in Section 7, it is felt that the spherical measurement is most representative of the true absorbance characteristic of the liquid, since it compensates for the effect of scattering. As shown on Figure 8-5, there is a significant difference in the computed intensities using either method, particularly during the periods which experienced higher levels of suspended solids and/or turbidity (responsible for scattering). When the direct UV absorbance coefficient is used in the intensity calculation, the resulting intensities are markedly lower than the intensities used with the spherical absorbance coefficient. Only the α_S based intensities are used in the subsequent application to the model.

Intensity Calculations for the Teflon System (Unit 3)

The average intensity in the teflon system was also computed utilizing the TULIP program. As with the quartz systems, a three dimensional coordinate system was constructed, with both the teflon tube and the lamps placed along the z-axis. The x and y coordinates effectively set the placement of the tubes and lamps with respect to each other. The terminus of the lamps and tubes were set at $z = 0.0$. An equal area grid was set up within the cross-section of the teflon tube, with the lamps surrounding the tube.

Two tube diameters were used during the term of the study. The diameter of the tube was 6.0 cm in all of 1982. This was switched to 8.9 cm for all of 1983. TULIP was used to determine the intensity in either case. A grid of 32 receivers was set for the smaller diameter tube, while a total of 80 were used for the larger tube. Only the six lamps immediately surrounding the teflon tube were found to have any impact on the intensity; in the case of the tubes at the top and the bottom of the vertical rows there would be only four lamps impacting the intensity calculation.


Lamp
9000
6000
5000
4000
3000
2000
Teflon tube (8.9 cm diameter)

Note: • Not to scale
• absorbance coefficient: 0.3 cm^{-1}
• intensity in μ Watts/cm^2

Figure 8-6. Examples of intensity calculation in a cross-section of the teflon tube.

Figure 8-6 presents a solution for the 8.9 cm teflon tube at a liquid absorbance coefficient of 0.3 cm^{-1}. The grid system is shown and the isointensity lines are drawn to demonstrate the distribution of intensity within the tube cross-section. This solution presumes that there are six lamps influencing the tube intensity. The lamp placements relative to the teflon tube are also shown on Figure 8-6.

Sensitivity runs were made to test the influence of the boundaries at the terminals of the lamps (and tubes). It was found that the intensity was greater than 90 percent of the average intensity (along the entire length) at approximately 10 to 15 cm from either end of the tubes. This is shown on Figure 8-7.

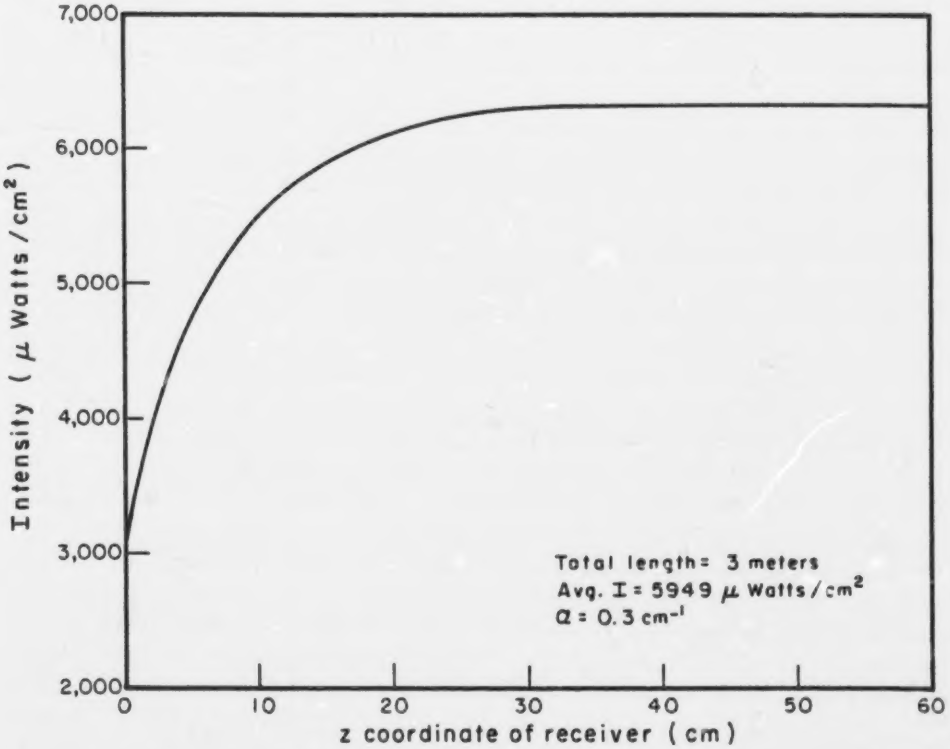


Figure 8-7. Calculated intensity of single receiver along length of teflon tube.

The final solutions for either size teflon tube are presented on Figure 8-8, which gives the calculated intensity as a function of the UV absorbance coefficient of the liquid. These solutions presume that: (1) the tube and lamp placements are as shown on Figure 8-6, and (2) there is 100 percent transmittance by the teflon wall. The intensity must be adjusted for the actual UV transmittance of the teflon under the given field conditions. This is done by simply multiplying the calculated intensity (Figure 8-8) by the actual teflon transmittance at 253.7 nm.

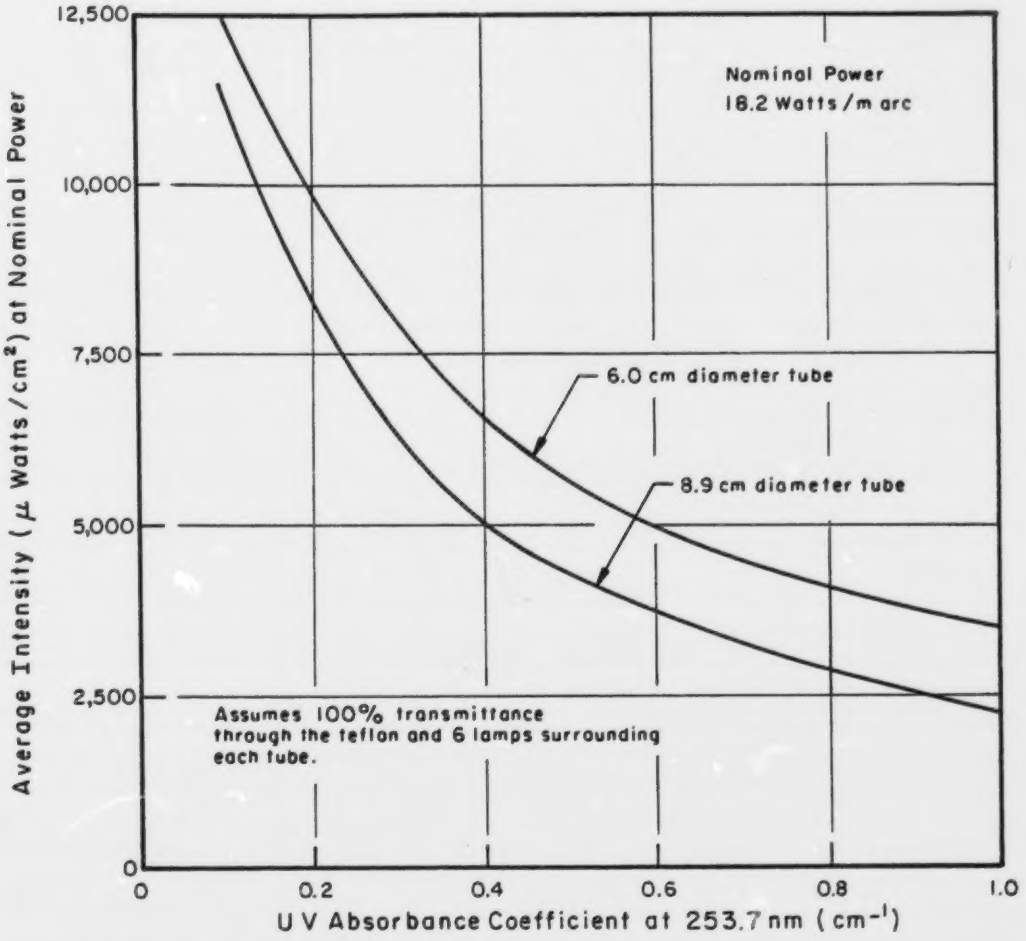


Figure 8-8. Calculation of intensity in teflon tubes as a function of the absorbance coefficient.

With regard to the Port Richmond project, estimates had been made of the teflon transmittance during selected periods of operation. These are summarized on Figure 7-18. Additionally, as with the quartz systems, the solution on Figure 8-8 uses the nominal output of the mercury arc lamp source (18.2 watts/meter arc); this must be adjusted to the actual lamp output under given field conditions. Since there is only the lamp to consider in this case (no quartz sleeve) one need only account for the aging of the lamp and its effect on output. Figure 7-19 presents the estimated output of a 0.9 meter lamp (nominal output of 14.3 watts) over an 8000 hour operating time. This same relative decrease in output with time was used for the 1.47 meter lamps used in the teflon system.

Figure 8-9 presents, chronologically, the estimated intensities for the teflon system at Port Richmond. These are based on the spherical absorbance coefficients, the estimated UV transmittance of the teflon (Figure 7-18) and the estimated output of the lamps at the 253.7 nm wavelength.

One further manipulation of the intensity calculation must also be performed to account for the boundary condition at the top and bottom of the vertical teflon tube rows. These tubes see only four lamps, whereas the internal tubes see six lamps. TULIP was used to determine the relative effects of each of the six lamps surrounding the tube. The analysis found that the two lamps immediately adjacent to the tube contributed 60 percent of the input, while the four outlying lamps each contributed 10 percent of the input. Thus, the boundary teflon tubes would have 80 percent of the intensity calculated for the internal tubes.

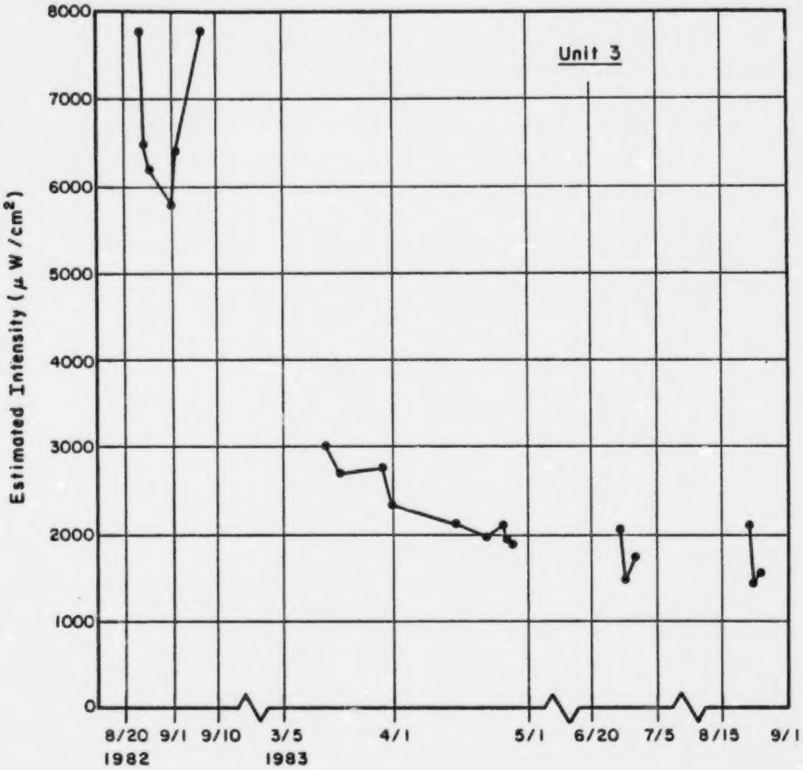


Figure 8-9. Chronological record of estimated intensities for Unit 3.

Estimate of Coliform Density Associated with Particulates

A key parameter influencing the performance of a UV system will be the extent to which bacteria will be protected by occlusion in suspended particulates in the wastewater. The UV absorbance measurements made by both the spherical and direct methods on total and filtered samples suggested strongly that the UV radiation (at 253.7 nm) is not absorbed to any significant degree by the particulates, but is simply scattered back to the carrying liquid. Thus, any coliforms which are heavily aggregated or are retained in the suspended matter typical of primary or secondary effluents will not be affected by the radiation. These densities will, in effect, form the baseline residual that a particular system can achieve for a given set of wastewater conditions. Further reductions would require process modifications to lower the levels of particulates in the wastewater.

A select set of the Port Richmond data were analyzed to estimate the total and fecal coliform densities which could be associated with the particulates. The measure of particulates in this case were the suspended solids and the turbidity. The data selected were those in which the sampling operating condition represented a Q/W ratio of less than 1.5 lpm/Watt. The reasoning behind this cut off was that in cases where the "dose" was very high it is reasonable to presume that any residual coliforms after exposure would be attributable to the coliforms retained in particulates. Analysis of the total data base indicated that an appropriate cut-off point would be at Q/W equal to 1.5.

Figure 8-10 presents the log effluent (after exposure) total and fecal coliforms as a function of the log effluent suspended solids concentration. This relationship was found to be linear, yielding coefficients of determination (r^2) of 0.46 for both total and fecal coliforms. Note that the data from both Units 1 and 2 were combined for the analysis presented on Figure 8-10; both sets had been analyzed separately and a test of slopes and intercepts indicated that the two linear regression lines were not significantly different. Linear regression analysis of the combined data set yielded the following expressions:

$$\text{Log Effluent Total Coliforms} = 2.01 \text{ Log SS} - 0.027$$

$$\text{Log Effluent Fecal Coliforms} = 1.96 \text{ Log SS} - 0.585$$

these can be transformed to:

$$\text{Total Coliform} = 0.918 \text{ SS}^{2.01} \tag{8-2}$$

$$\text{Fecal Coliform} = 0.260 \text{ SS}^{1.96} \tag{8-3}$$

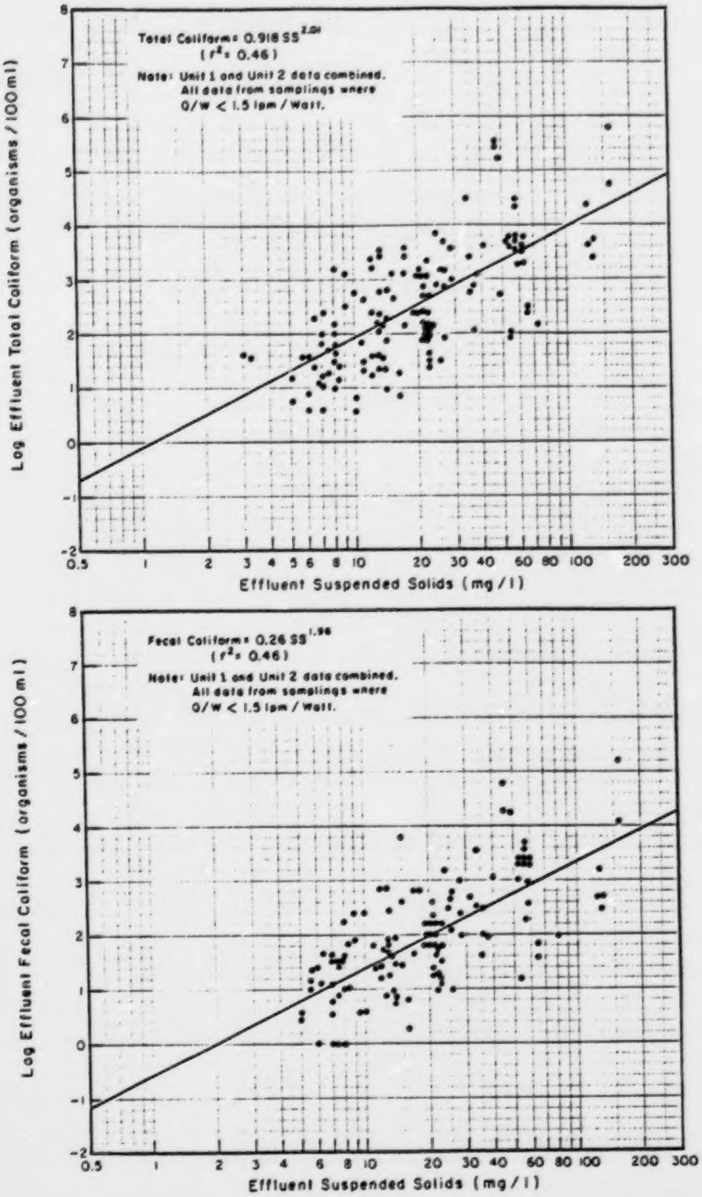


Figure 8-10. Estimate of the residual total and fecal coliform density associated with particulates as a function of suspended solids.

The data base is large and covers a significantly wide range: approximately four orders of magnitude for the coliform data and one order of magnitude for the suspended solids data. Thus, the expressions presented as Equations 8-2 and 8-3 are considered good estimates of the coliform densities associated with particulates and unaffected by UV radiation.

A similar analysis was performed using the turbidity as the index of particulate levels. These data are presented on Figure 8-11. Again, the combined data sets of Units 1 and 2 were analyzed and the log coliform density as a function of log turbidity relationship was found to be linear. The coefficients of determination were found to be 0.46 and 0.48 for the total and fecal coliforms, respectively. Linear regression analysis yielded the following expressions:

$$\text{Log effluent Total Coliform} = 1.55 \text{ Log turbidity} + 1.53$$

$$\text{Log effluent Fecal Coliform} = 1.46 \text{ Log turbidity} + 1.03$$

These can then be transformed:

$$\text{Total Coliform} = 33.9 \text{ turbidity}^{1.55} \tag{8-4}$$

$$\text{Fecal Coliform} = 10.7 \text{ turbidity}^{1.46} \tag{8-5}$$

Within the context of this report, the expressions based on the suspended solids will be used for subsequent application of the proposed disinfection model. Although either the suspended solids or turbidity were found to provide good estimates of the residual coliform densities attributable to the particulates, the suspended solids measurement is preferred for further analysis because it is the more common monitoring parameter in the wastewater treatment field.

On the basis of the regressions presented in Figure 8-10, the term $L_{\text{particulate}}$ in Equation 8-1 is estimated as follows:

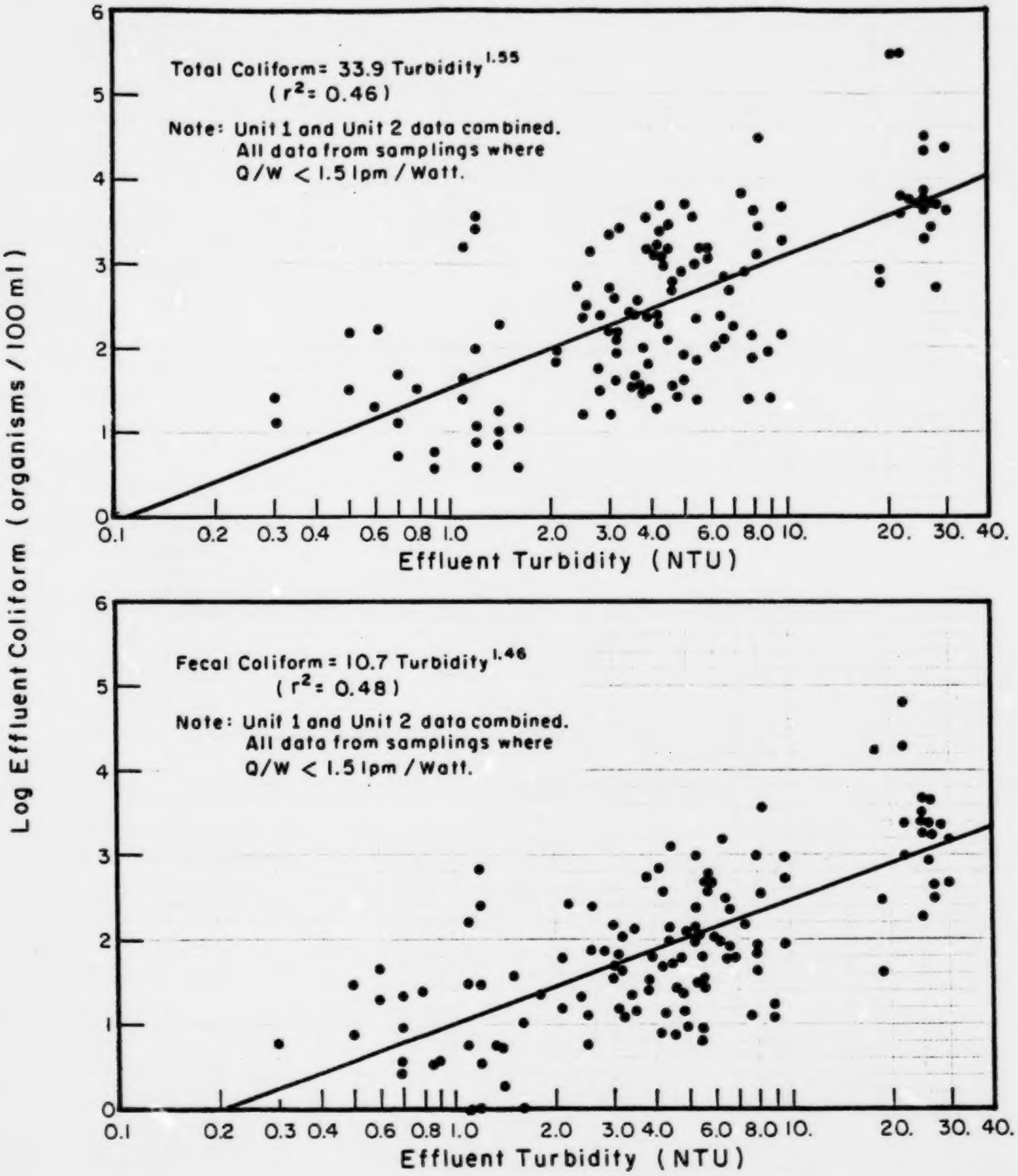


Figure 8-11. Estimate of the residual total and fecal coliform density associated with particulates as a function of turbidity.

$$\text{Total Coliforms}_{\text{particulate}} = 0.9\ \text{SS}^2 \tag{8-6}$$

$$\text{Fecal Coliforms}_{\text{particulate}} = 0.25\ \text{SS}^2 \tag{8-7}$$

Estimate of the Inactivation Rate as a Function of the Intensity

The inactivation rate coefficient, K, contained in the disinfection model can be expressed as a function of the UV intensity in a system. Thus, for a given time of exposure (or distribution of time) the rate of inactivation will increase with an increase in the intensity. In order to estimate this relationship for the Port Richmond application, it was once again necessary to select a specific segment of the data base. In this case, the required samplings were those in which the operating conditions would not allow for complete kill at some point within the unit. In other words the apparent "dose" was low enough such that a significant coliform density would still be evident in the exposed effluent. This allows a valid estimate of the rate of inactivation in a specific sampling utilizing the initial and final coliform densities.

Figure 8-12 is presented to demonstrate how the data subset was developed for the subsequent estimation of the inactivation rate. The figure displays the log survival ratio of fecal coliform as a function of the "apparent dose" for either Unit 1 or Unit 2. The apparent dose is derived by multiplying the calculated average intensity by the theoretical detention time of the unit (void volume/flow rate) corresponding to the conditions for each sampling. A cutoff point was then established from this figure; all data developed at an apparent dose of less than 30,000 μWatt-sec/cm^2 would be utilized for the rate calculations. It was felt that the dose-response was linear below this point with no evidence of the tailing effects seen at apparent dose levels greater than 50,000 μWatt-sec/cm^2.

Once the data subset was established, the rate coefficient was estimated for each sampling by manipulation of the proposed model equation to solve for K (recall Equation 8-1). Estimates are first made of the

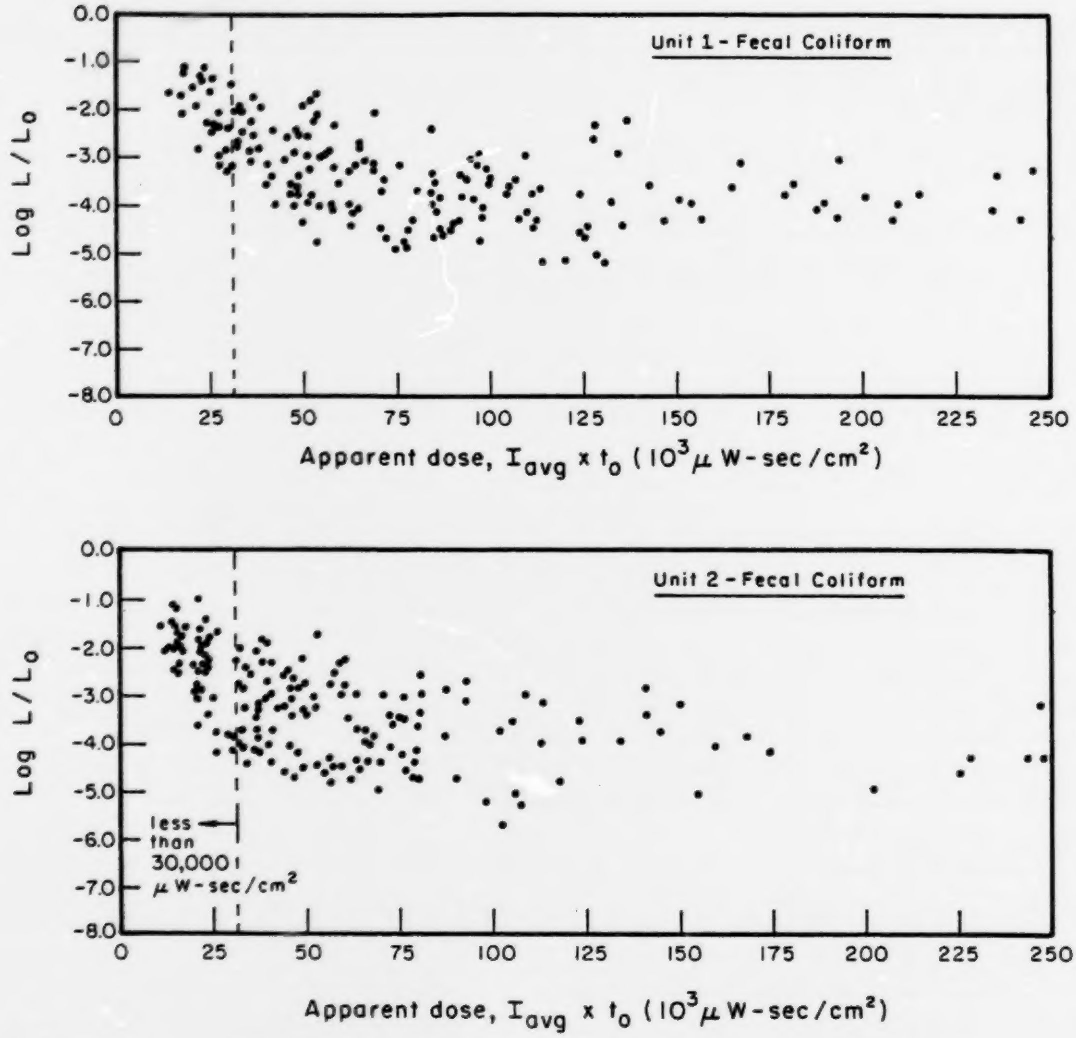


Figure 8-12. Unit performance as a function of the apparent dose.

$L_{particulate}$ from the suspended solids data and Equations 8-6 and 8-7; this is then subtracted from the measured coliforms after exposure. Thus,

$$L' = L - L_{particulate} \tag{8-8}$$

and,

$$\ln (L'/L_o) = (ux/2E) - (ux/2E) [1 + (4KE/u^2)]^{1/2} \tag{8-9}$$

Solving for K, the expression becomes:

$$K = [u^2(P^2 - 1)]/4E \tag{8-10}$$

where,

$$P = 1 - [\frac{2E \ln (L'/L_o)}{ux}] \tag{8-11}$$

The rate K has the units (second^{-1}); Equation 8-10 can be solved for K for each sampling. The inputs are the observed initial and final (adjusted for particulates) coliforms, the velocity based on the observed flow rate, the x dimension based on the operating condition of the unit, and the observed dispersion coefficient, E, for the particular system. These estimates of the inactivation rate were calculated for each of the samplings in the data subset and then correlated to the calculated intensities for each of the samplings.

The correlation of the Log K as a function of the Log I_{avg} was found to be linear. The data from both units were combined in order to yield a significant intensity range. The data are presented on Figure 8-13 for the total and fecal coliforms. Linear regression analysis yielded the following expressions:

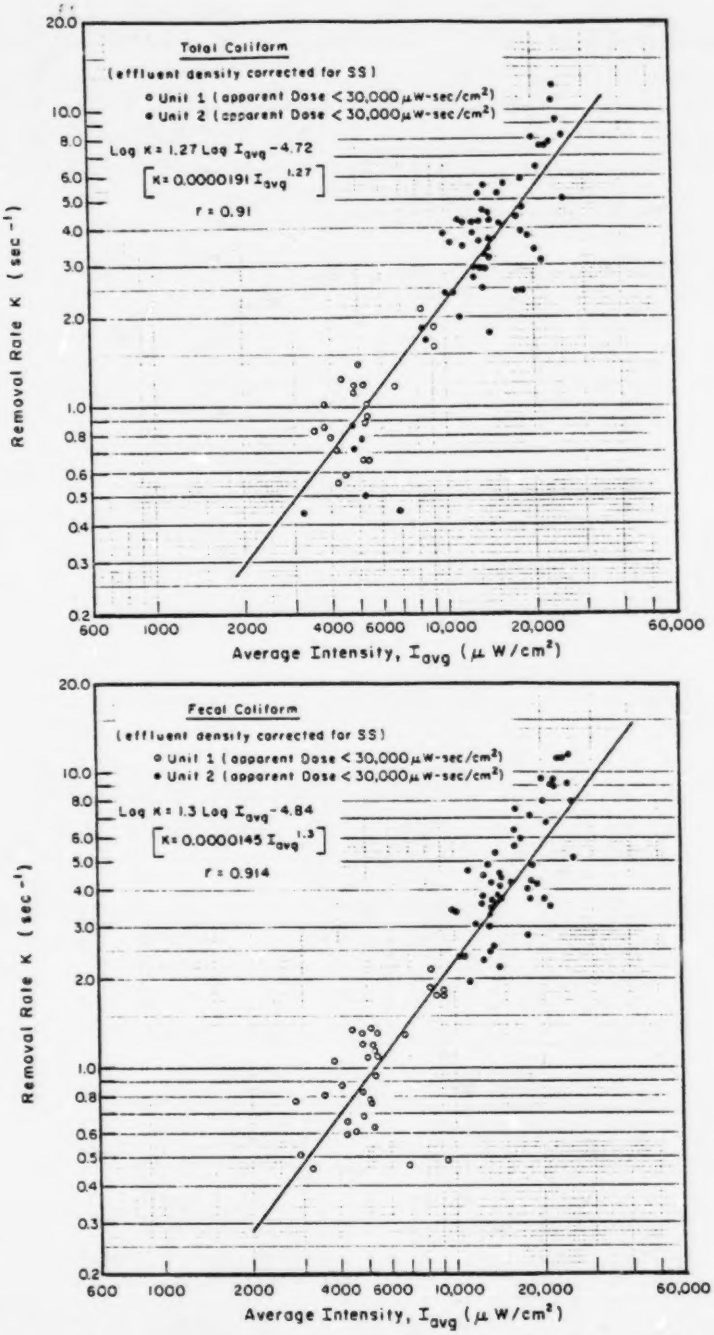


Figure 8-13. Estimation of the inactivation rate for total and fecal coliforms as a function of the calculated average intensity.

Total Coliforms

$$\text{Log } K = 1.27 \text{ Log } I_{avg} - 4.72 \quad \ldots \quad r^2 = 0.83 \qquad (8\text{-}12)$$

Fecal Coliforms

$$\text{Log } K = 1.30 \text{ Log } I_{avg} - 4.84 \quad \ldots \quad r^2 = 0.84 \qquad (8\text{-}13)$$

The two expressions can be shown to be equivalent at I_{avg} levels between 1000 and 40,000 μWatts/cm^2. For this reason one equation was utilized for subsequent application to the disinfection model. This is the expression based on the fecal coliform data, which when transformed can be written:

$$K = 0.0000145 \; I_{avg}^{1.3} \qquad (8\text{-}14)$$

where K is the inactivation rate in sec^{-1}, and I_{avg} is the average computed intensity in μWatts/cm^2.

CALIBRATED DISINFECTION MODEL

Based on the preceding discussions regarding the calibration of the model parameters, Equation 8-1 takes on the following general format:

$$L = L_o \exp \left\{\frac{ux}{2E} \left[1 - \left(1 + \frac{4E\, a I_{avg}^{\,b}}{u^2}\right)^{1/2}\right]\right\} + cSS^d \qquad (8\text{-}15)$$

The coefficients a,b,c, and d are specific to a given wastewater application and reflect the site specific sensitivity to UV and the impact of the particulates. These are approximated by direct calibration of the model to an appropriate set of data. The values of these coefficients derived for the Port Richmond application are summarized as follows (where I_{avg} is in μWatts/cm^2 and suspended solids is in mg/1):

$a = 0.0000145$

$b = 1.3$

$c = 0.25$ for fecal coliforms and 0.9 for total coliforms

$d = 2.0$ for both total and fecal coliforms

The dispersion coefficient, E, had been discussed earlier. An $E = 1.5$ cm^2/sec was assigned to Unit 1; the E for Unit 2 is 15 cm^2/sec. The dispersion coefficient had not been directly measured on Unit 3; given the long tube design configuration, a low E of 0.5 cm^2/sec was assigned to the system, presuming it to have hydraulic characteristics which closely approximate plug flow. Of the remaining input parameters, u will be defined by the system design configuration and flow rate; the x is set by system configuration. I_{avg} is set by the measured spherical absorbance coefficient and the given lamp design and operating condition for the system. The initial density, L_o, will be characteristic of the wastewater.

To determine the effectiveness of the model calibration, the observed residual coliform density was compared to the calculated residual density for each sampling in the total data base. For convenience an example is provided to demonstrate the calculation of the residual density for a given sampling. Consider Sampling No. 369 for Unit 2, conducted April 11, 1983:

Flow = 2573 lpm (42.9 lps)

Absorbance coefficient, $\alpha_S = 0.278\ cm^{-1}$

Suspended solids = 8.8 mg/l

Initial fecal coliform density = 230,000 organisms/100ml

System operation: 2 lamp banks on (58 of 60 lamps operating)

$x = 26.4$ cm; $V_v = 50.2$ liters

$u = 26.4$ cm/(50.2 l/42.9 lps) = 22.56 cm/sec

$E = 15\ cm^2/sec$

Lamp output: From Figure 7-19 the average UV output on the given date was approximately 38 percent of the nominal output of the lamps (5.5 watts actual/14.3 watts nominal).

From Figure 8-4 the average computed intensity for Unit 2 at nominal output and an absorbance coefficient of 0.278 cm^{-1} is 37500 μWatts/cm^2.

I_{avg} = 0.38 (37500) = 14250 μWatts/cm^2

Recall that the coefficients in Equation 8-15 have the value

a = 0.0000145
b = 1.3
c = 0.25
d = 2.0

Substituting the appropriate values into Equation 8-15 yields:

L calculated = 4760 organisms/100ml
(log L calculated = 3.68)

This can then be compared to:

L observed = 4000 organisms/100ml
(log L observed = 3.60)

This same calculation procedure was used for each of the samplings in the Port Richmond project. These estimates are presented on Figures 8-14 and 8-15 for Units 1 and 2 respectively. As shown, the secondary and primary data bases were combined. In each case a regression analysis was performed to determine the correlation of the log effluent coliform (observed) with the log effluent coliform (calculated). The resulting equation and regression line are also presented on the figures. Ideally, the slope of the regression equation should be equal to 1.0, with the intercept equal to 0.0. Similar calculations were performed for Unit 3; these are presented on Figure 8-16.

An analysis was conducted, utilizing Student's t-test, to determine if the regression lines were significantly different from the ideal line. The

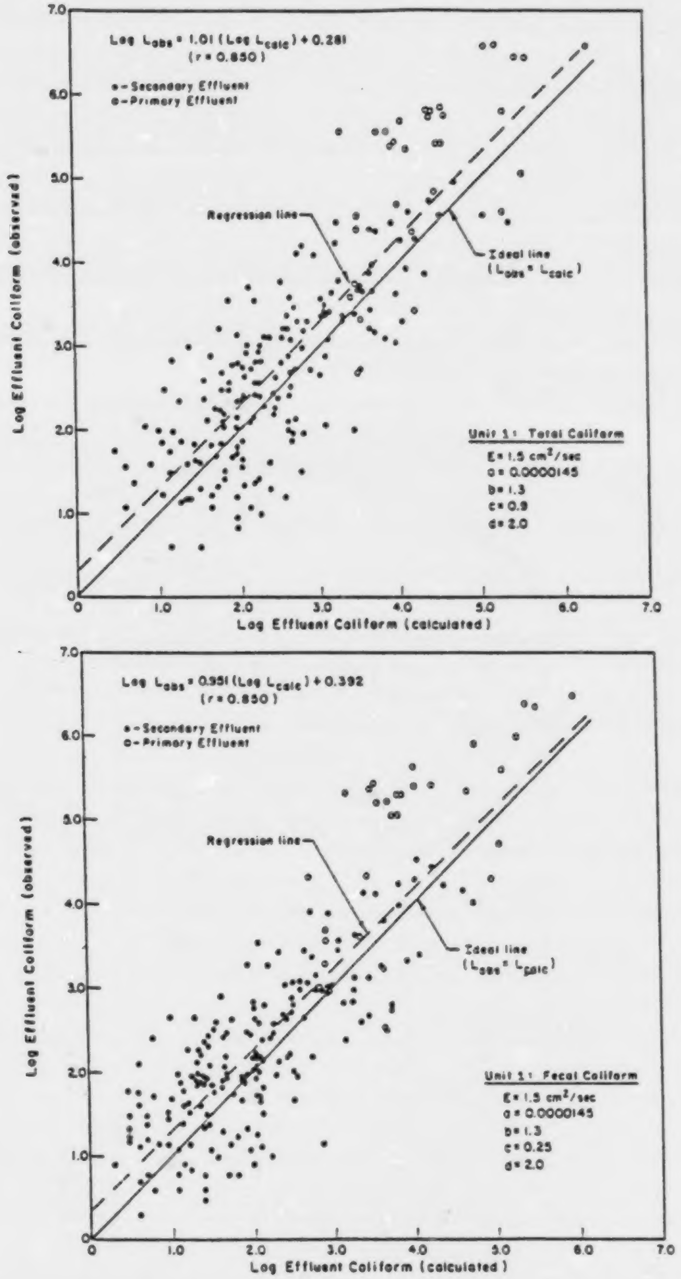


Figure 8-14. Comparison of disinfection model estimates to observed effluent densities for Unit 1, total and fecal coliforms.

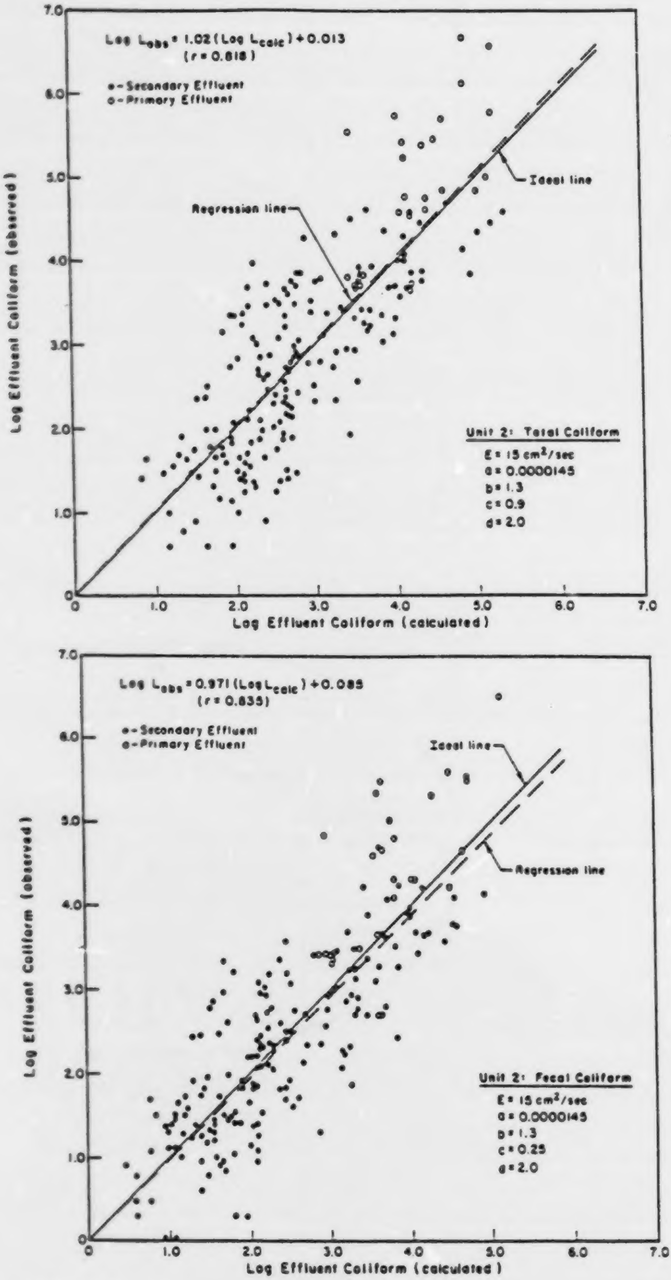


Figure 8-15. Comparison of disinfection model estimates to observed effluent densities for Unit 2, total and fecal coliforms.

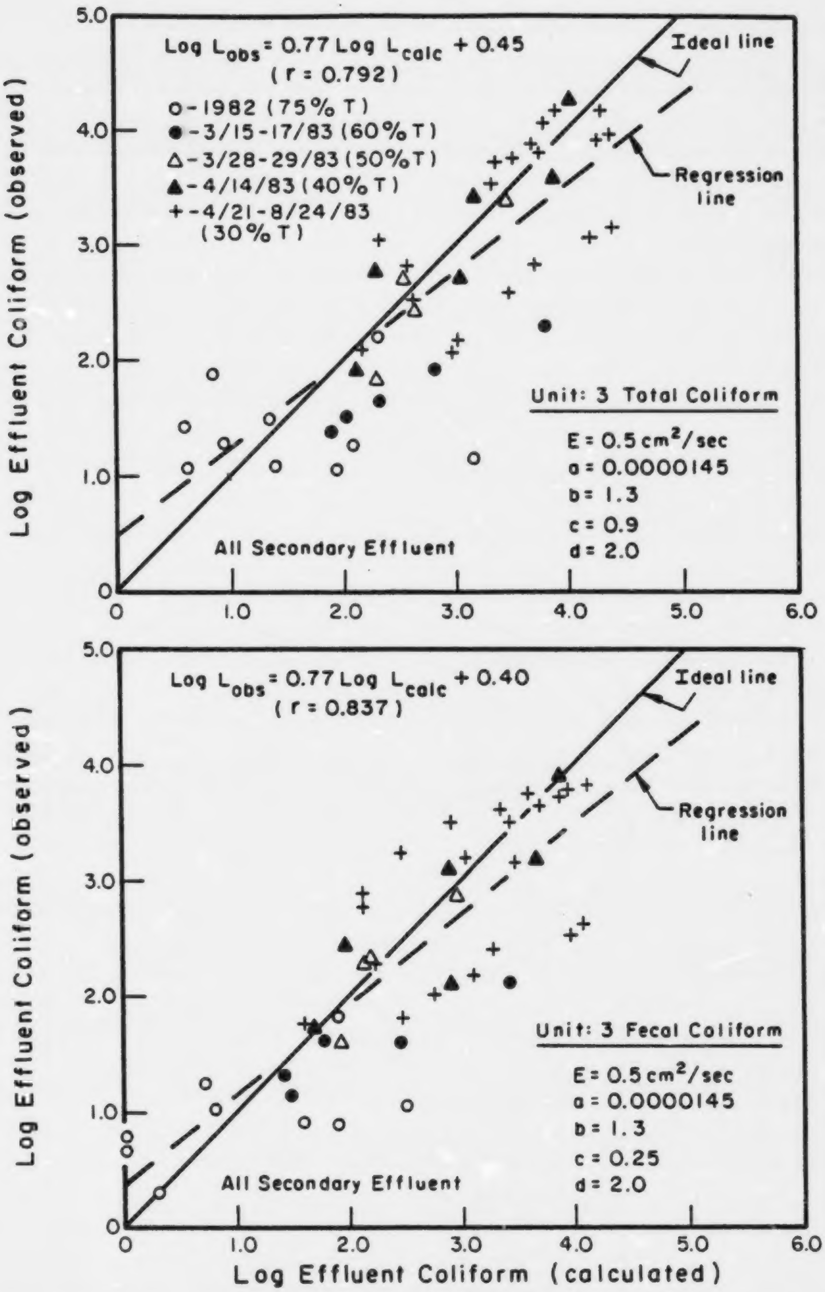


Figure 8-16. Comparison of disinfection model estimates to observed effluent densities for Unit 3, total and fecal coliforms.

null hypotheses tested were that the regression line slopes and intercepts were not significantly different from the ideal (slope of 1.0, and an intercept of 0.0). In the comparison of slopes against the ideal, the test failed to reject at a significance level of one percent for all three units, both total and fecal coliforms. (In the case of Units 1 and 2, the test also failed to reject at a signficiance level of five percent.) Similarly, except for the Unit 1 fecal coliform regression, the test failed to reject (at a one percent significance level), that the intercepts were significantly different from 0.0. The hypothesis was rejected in the case of Unit 1, fecal coliforms, although marginally.

A residuals analysis was also performed to determine if the independent variables in the model produced a residual effect which was unexplained by the model expression. The difference between the observed and calculated densities (LogL_{obs} - LogL_{calc}) was regressed against each of the major independent variables influencing the model calculation. The slope and intercept of the regression line would aproximate zero if there was no residual trend. That is, the variable is not significantly correlated with the difference (residual) between the observed and calculated densities. The variables tested were:

- Ratio of flow to meters of lamp arc, Q/meter arc. In the case of Unit 3, this was Q/meter of tube. This ratio is representative of the variability associated with the velocity term in the model expression.
- Initial density, L_o.
- Suspended Solids, SS.
- Intensity; this is the adjusted intensity for each sampling and is representative of the variability associated with the absorbance coefficient.
- Inactivation rate, K.

Examples are provided on Figures 8-17 and 8-18 for Unit 2, total coliforms. Regressions are shown with the ratio Q/meter arc and the intensity on Figure 8-17; at the five percent significance level, there was no significant correlation of either variable with the residual. Figure 8-18

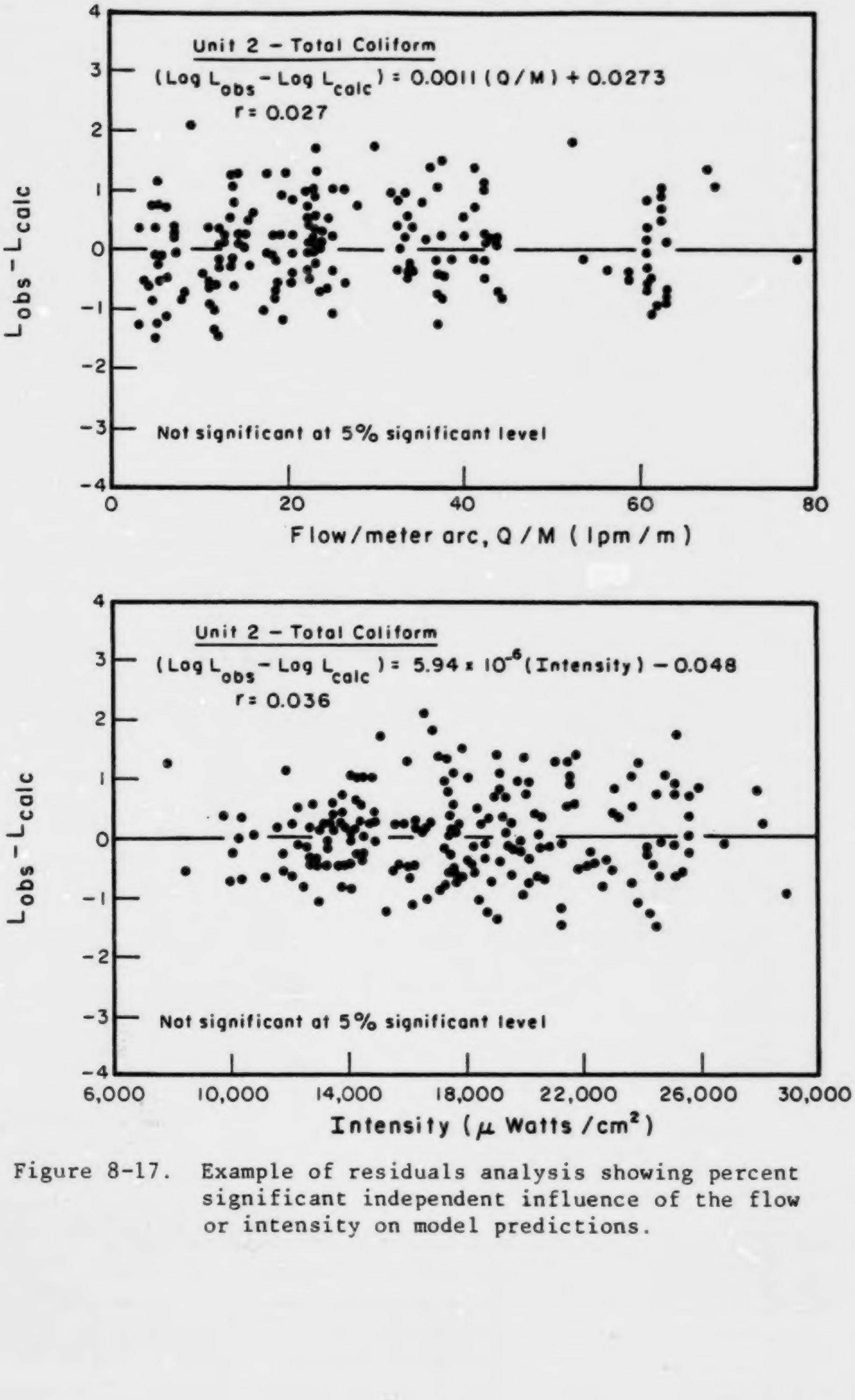


Figure 8-17. Example of residuals analysis showing percent significant independent influence of the flow or intensity on model predictions.

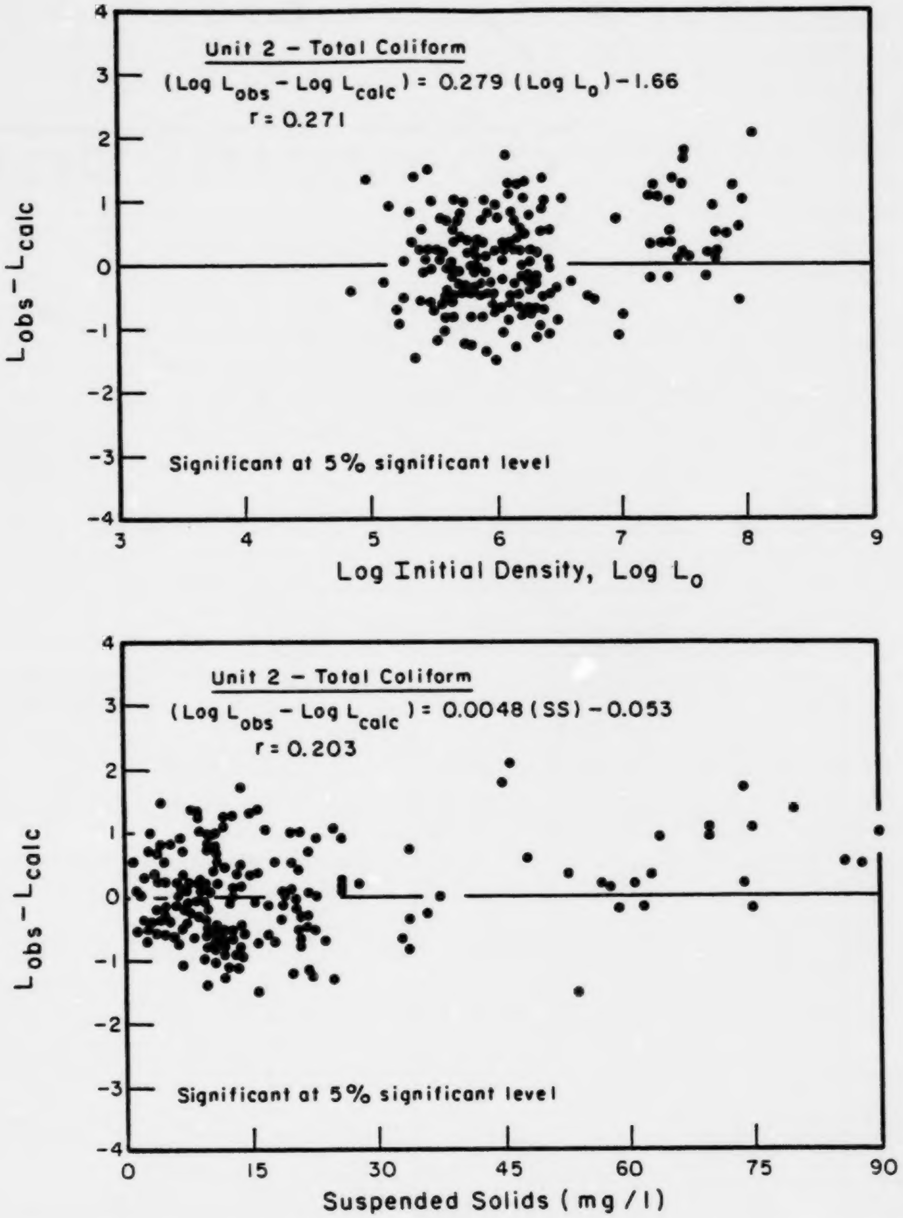


Figure 8-18. Example of residuals analysis showing significant independent influence of the initial density and suspended solids on the model prediction.

presents similar regressions with the initial density (L_o) and suspended solids (SS); in this case, a significant correlation was determined at the five percent level. The analyses indicate a positive bias to the residual at the higher levels of either L_o or suspended solids.

The results of the residuals analyses are summarized in Table 8-1. Significance is noted at the one percent level. Suspended solids and the initial densities were found to be significant in the case of Units 1 and 2. The flow rate was found to be affecting the model prediction in the case of Unit 3.

TABLE 8-1. CORRELATION OF ($LogL_{obs}-LogL_{calc}$)
WITH INDEPENDENT MODEL PARAMETERS

Parameter	Correlation Coefficient, r Fecal Coliform	Correlation Coefficient, r Total Coliform
Unit 1		
Flow/Meter Arc	0.011 (NS)	0.01 (NS)
Initial Density (L_o)	0.323 (S)	0.323 (S)
Intensity	0.160 (NS)	0.163 (NS)
Suspended Solids	0.175 (NS)	0.22 (S)
Inactivation Rate, K	0.158 (NS)	0.16 (NS)
Unit 2		
Flow/Meter Arc	0.088 (NS)	0.027 (NS)
Initial Density (L_o)	0.224 (S)	0.27 (S)
Intensity	0.054 (NS)	0.036 (NS)
Suspended Solids	0.199 (S)	0.203 (S)
Inactivation Rate, K	0.057 (NS)	0.035 (NS)
Unit 3		
Flow/Meter Tube	0.428 (S)	0.472 (S)
Initial Density (L_o)	0.10 (NS)	0.106 (NS)
Intensity	0.165 (NS)	0.156 (NS)
Suspended Solids	0.01 (NS)	0.016 (NS)
Inactivation Rate, K	0.16 (NS)	0.149 (NS)

NS - not significant
S - significant

Overall, the analyses discussed above suggest that the model is successfully predicting the densities that would occur under different operating conditions. The regression lines are shown to be very similar to the ideal line. The analyses do, however, indicate that there may be some bias being caused by the higher levels of the initial density and the suspended solids. These would represent the primary effluent data for Units 1 and 2. The flow rate in Unit 3 was found to be causing a positive bias at the lower flow levels; Unit 3 was not tested with primary effluent.

There may be an underlying cause of the biases implied by the above analyses. The primary effluent tests were conducted at predominantly low flows. The discussions in Section 7 suggest that laminar conditions may have existed at these flow levels; the effect of the higher densities and solids will be exacerbated by such a condition. If stratified flow conditions exist in the non-uniform intensity field, it is likely that higher densities will be observed than are predicted, particularly since the model assumes turbulence. This will be especially noted, as is the case, in Unit 1 and 3, which have the greater range of intensities within a given intensity field. Although there is no apparent bias observed from the flow to Units 1 and 2, there may be a bias implied by coupling the effects of the higher initial densities and suspended solids to the fact that these were studied under low flow conditions.

Effect of Non-turbulent Flow Condition on Model Calibration

The use of the dispersion coefficient in the context of the proposed model assumes that there are turbulent conditions throughout the operating flow range. The analysis presented on Figure 7-13 in Section 7 suggests that this may not have been the case for the two quartz systems at the lower flows; the headloss measurements as a function of flow gives evidence of a transition from laminar to turbulent at a flow of approximately 2000 lpm for Unit 1 and 1000 lpm for Unit 2. There is no direct method, with the data available, to directly account for this effect on the model response. Since it is expected that the effects of dispersion would be enhanced in a laminar flow environment, the dispersion coefficients derived for either quartz unit were artificially increased for the samplings in which the flow rates were less than the estimated transitional flow rate. The intent was to determine the effects of increased dispersion at the lower flow rates. This would simulate the effect of stratified flow, whereby a fraction of the liquid would pass only through the lower intensity regions of the non-uniform intensity field (see Figures 8-1 and 8-6).

The dispersion coefficient, E, was increased from 1.5 to 15 cm^2/sec for flow rates less than 2000 lpm for Unit 1, and left at 1.5 cm^2/sec for flows greater than 2000 lpm. The results are presented on Figure 8-19 for total and fecal coliforms. The correlation of the observed versus predicted coliform density is obviously improved, with the regression line approximating the ideal line. In this case the intercepts and slopes were found not to be significantly different from the ideal condition.

In similar fashion, the observed versus predicted densities for Unit 2 are presented on Figure 8-20. In this case, the dispersion coefficient was increased from 15 to 30 cm^2/sec for flows less than 1000 lpm; the value of E was left at 15 cm^2/sec for flows greater than 1000 cm^2/sec. Again, there is an improvement in the correlation; the regression line is shown to effectively overlay the ideal line in this case.

A residuals analysis was again performed for Units 1 and 2 to determine the impact on modifying the E. The results are summarized in Table 8-2. The initial density and suspended solids are no longer significant for the fecal colform regressions for either unit. Only the initial density remained significant with regard to the total coliform, but less significant than the levels presented in Table 8-1.

Although the above analysis is not technically rigorous, it does show the importance of the hydraulic characteristics of a unit. System designs need to consider mixing characteristics and should encourage a turbulent condition through the expected operating flow range. Alternative configurations would be staggered lamps, or closer spacing (as with Unit 2, which was not as markedly affected in the above analysis).

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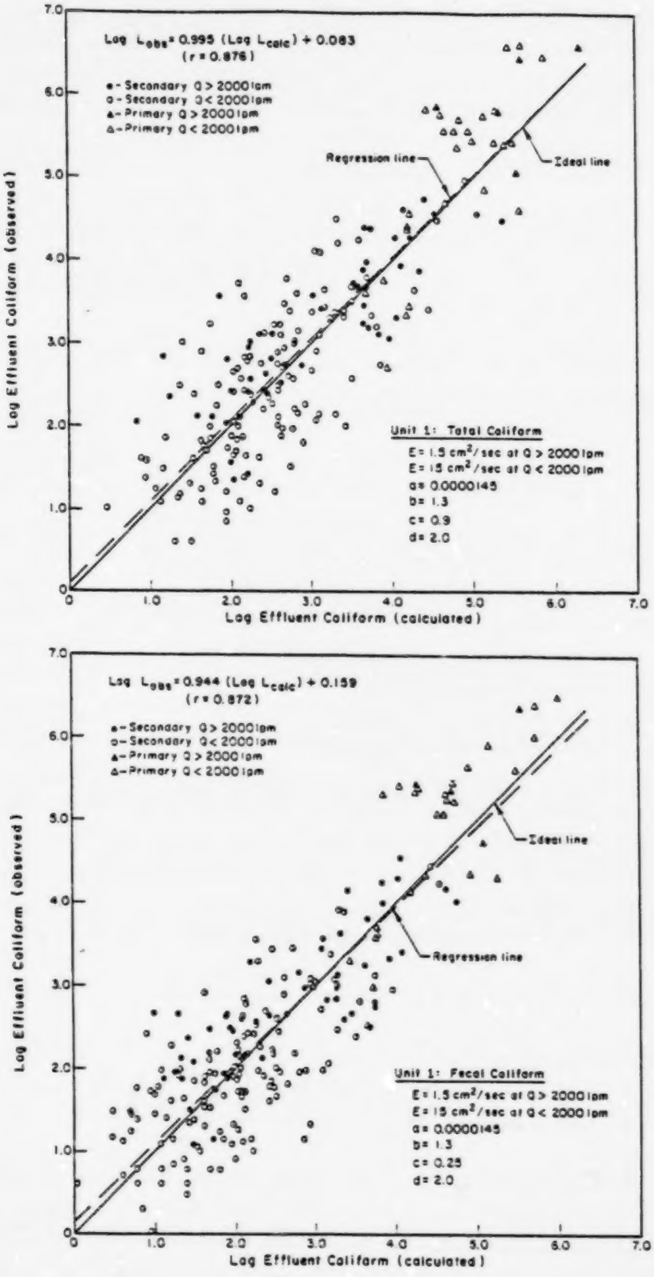


Figure 8-19. Effect of adjusting dispersion coefficient on model predictions, based on estimate of laminar/turbulent flow conditions.

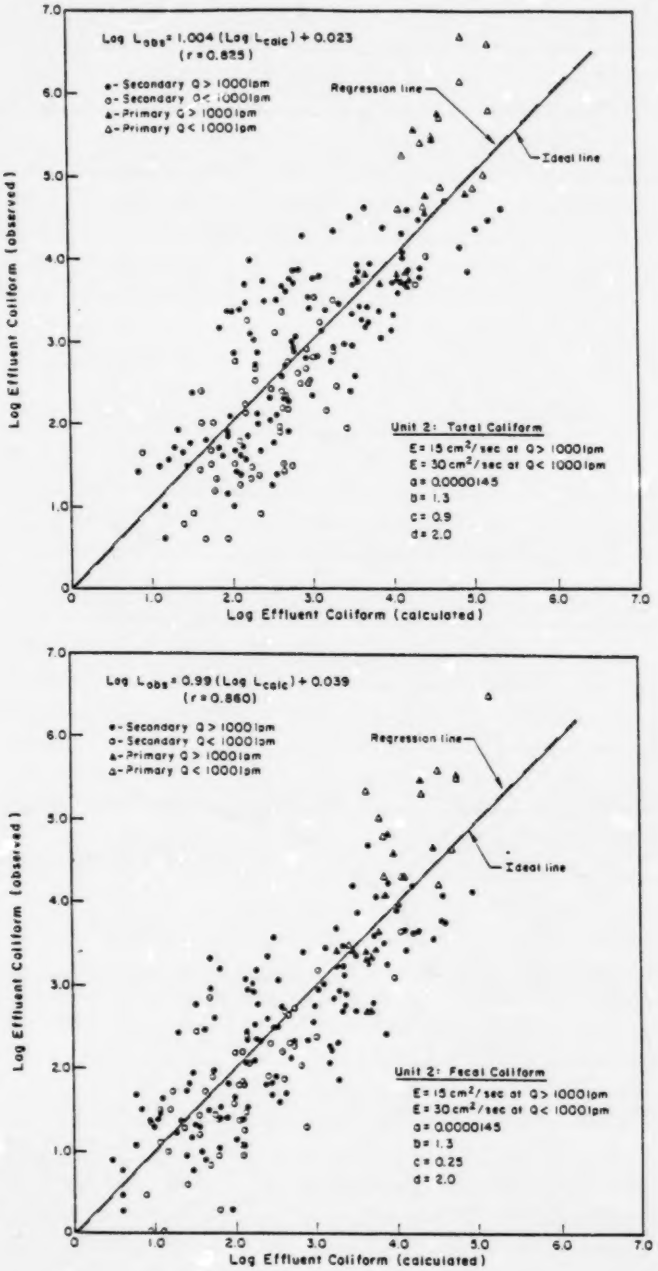


Figure 8-20. Effect of adjusting dispersion coefficient on model predictions based on estimate of laminar/turbulent flow conditions.

TABLE 8-2. CORRELATION OF ($\mathrm{LogL}_{obs}-\mathrm{LogL}_{calc}$) WITH INDEPENDENT MODEL PARAMETERS AFTER ADJUSTING VALUE OF E

	Correlation Coefficient	
	Fecal Coliform	Total Coliform
Unit 1[a]		
Flow/Meter Arc	0.081 (NS)	0.050 (NS)
Initial Density (L_o)	0.109 (NS)	0.189 (S)
Intensity	0.016 (NS)	0.08 (NS)
Suspended Solids	0.171 (NS)	0.142 (NS)
Inactivation Rate, K	0.017 (NS)	0.079 (NS)
Unit 2[b]		
Flow/Meter Arc	0.014 (NS)	0.085 (NS)
Initial Density (L_o)	0.162 (NS)	0.222 (S)
Intensity	0.012 (NS)	0.095 (NS)
Suspended Solids	0.181 (NS)	0.184 (NS)
Inactivation Rate, K	0.008 (NS)	0.094 (NS)

[a] E = 1.5 cm^2/sec at Q>1000 lpm
15 cm^2/sec at Q<2000 lpm
[b] E = 15 cm^2/sec at Q>1000 lpm
30 cm^2/sec at Q<1000 lpm

NS - not significant (1 percent)
S - significant (1 percent)

DESIGN EXAMPLES UTILIZING THE DISINFECTION MODEL

Once the mathematical model has been calibrated to a given in-field condition, it can then serve as an effective tool in the design and in the operation of a UV disinfection system. A new system can be evaluated to assure that it is adequately and efficiently sized for a particular wastewater application. The system can also be studied to determine the appropriate operating parameters under any number of wastewater conditions the plant may experience. In similar fashion, an existing unit can be evaluated to optimize its operations or to determine its deficiencies in the case of troubleshooting non-performance.

The proposed model has been calibrated to the Port Richmond wastewater characteristics, as presented in the preceding discussions. In-field data have been utilized to determine those coefficients which are directly affected by the characteristics of a particular plant effluent. These are a and b, which set the bacterial inactivation rates as a function of intensity, and the coefficients c and d, which approximate the density of coliforms associated with the particulates carried by the effluent. For the subsequent model applications, the values of these coefficients are:

$a = 0.0000145$
$b = 1.3$
$c = 0.25$ for fecal coliforms
$d = 0.9$ for total coliforms

All other variables in the model expression become a function of the particular configuration of the unit (lamp sizing, lamp arrangement, system dimensions, and dispersion characteristics), and the wastewater characteristics (flow rate, absorbance coefficient, suspended solids, and initial density).

The calibrated model can now be used to evaluate a matrix of system designs for the Port Richmond plant. The three unit configurations tested at the plant will be studied for the sake of convenience and to maintain continuity in the context of this report. The reader should understand, however, that once the expression has been calibrated to a specific wastewater condition, a wide ranging matrix of system configurations can be considered. The one parameter that would be affected would be the dispersion coefficient, E, which may change with differing lamp arrangements (e.g., lamps which are parallel to the direction of flow versus being perpendicular). Any final design calculation would require confirmation of a system's hydraulic characteristic, as defined by the dispersion coefficient.

Description of Systems to be Utilized in the Design Examples

A series of design solutions have been developed for the three system configurations. The intent of the following examples is to present the design protocol by which the reader can develop system solutions and evaluate the design sensitivity to the major design parameters.

The three units to be evaluated are:

Unit 1: widely spaced submerged quartz system
Unit 2: closely spaced submerged quartz system
Unit 3: system utilizing teflon tubes

The two quartz units are to have the liquid flow perpendicular to the lamps. Each lamp is to be sheathed in a quartz sleeve with an outer diameter of 2.3 cm. The quartz are arranged symmetrically, whereby the centerlines are vertically and horizontally arrayed as shown on Figure 6-3. The only difference in the configuration of the two units is the spacing between quartz outer surfaces: this will be 5.0 cm for Unit 1 and 1.25 cm for Unit 2. The spacing is uniform throughout the units.

The third system, Unit 3, will utilize 8.9 cm diameter teflon tubes to carry the wastewater. Lamps (unsheathed) will be arranged to surround the tubes, running parallel along the length of each tube. The system will be comprised of alternating vertical rows of lamps and tubes; the vertical stacking will be on 15 cm centerline spacings for both the tubes and lamps. Horizontally, the centerline spacing will also be 15 cm.

All three systems will utilize low pressure mercury arc lamps with a rated nominal output of 18.2 watts/meter arc at the 253.7 nm wavelength. Additionally, it is suggested that these lamps have vycor (or equivalent) envelopes, not quartz.

Determining the Calculated Average Intensity within the System

The average intensity within a given lamp configuration must first be determined using the point source summation method. These solutions have already been established for the three configurations being considered, using the TULIP program. The reader is referred to Figures 8-4 and 8-8 which presented the average calculated intensity as a function of the UV absorbance coefficient of the wastewater. The solutions presented on Figure 8-4 are for the two quartz units; Figure 8-8 presents the solution for the teflon tube configuration (refer to the line for the 8.9 cm tube). In both cases, the calculation presumes 100 percent transmittance to the liquid; the resulting intensity must be subsequently adjusted for losses of energy (at the 253.7 nm wavelength) due to lamp deterioration and/or absorption by the quartz or teflon enclosures.

Calibrated Model Solutions for the Three Unit Configurations

The following discussions of the model application will demonstrate its utility and the procedure to optimize the design of a system. An appropriate starting point may be to present the basic design conclusions which were derived from the use of the model:

- The design objective for an efficient system is to maximize the loading to the system. The loading is defined as the ratio of the flow rate to the nominal UV wattage in the system (Q/W_n).

- Conversely, the maximum loading implies that the time of exposure is to be kept to an allowable minimum, as is set by the loading for a specific lamp configuration.

- Once the loading is established (and, in effect the nominal exposure time) the secondary design objective must be addressed. This is to assure a minimum velocity at the design loading; the minimum velocity will be a function of the dispersion characteristics of the system. The minimum velocity will be set, at a given nominal exposure time, by the dimension x, which is the distance traveled in the reactor.

The premise that the loading (Q/W_n) sets the nominal exposure time should be understood. Figure 8-21 displays the computed nominal time as a function of the loading for each of the three design examples. Consider the computation for Unit 2: the rectangular liquid volume associated with a single quartz is 3.55 cm (quartz diameter, 2.3 cm, plus the spacing) times 3.55 times the arc length, minus the volume of the quartz sleeve itself. This liquid volume is designated the void volume, V_v. There is also the nominal wattage (W_n = 18.2 W/m x 1.47 m) associated with each lamp: thus the flow rate and the void volume for a specific lamp arrangement can be normalized to the nominal wattage. The nominal exposure time can be expressed:

$$t_n = (V_v/W_n)/(Q/W_n) \tag{8-16}$$

The ratio of V_v/W_n for the Unit 1 is 0.048 $1/W_n$; thus at a Q/W_n of 1.0 lpm/W the nominal detention time is 0.048 minutes, or 2.9 seconds. Similar calculations can be performed for the widely spaced Unit 1.

The teflon system must be treated somewhat differently to account for the effect of the number of vertical rows in a module on the power efficiency (the reader is referred to the discussion in Section 7 and to Figure 7-20). The solution on Figure 8-21 presumes that there are 1.1 meters of lamp arc per meter of teflon tube (this assumes a module size of approximately 10 vertical rows). This yields 20 watts per meter of tube (at a lamp rating of 18.2 watts/meter of arc). The volume of one meter of the 8.9 cm diameter tube is 6.2 liters; thus, the V_v/W_n ratio for the teflon is 6.2/20, or 0.31 $1/W_n$.

Let us now consider the concept of the fixed performance at a given loading. Since the loading sets the time of exposure, the rate of inactivation will set the performance of the system, as defined by the log of the survival ratio, L/L_o. This performance will always be the same regardless of the dispersion coefficient, as long as the velocity (and by implication, the dimension x) is greater than the minimum velocity. Figure 8-22 demonstrates this for Unit 2. Solutions are shown at an intensity of 15000 μWatts/cm^2, which yields a rate

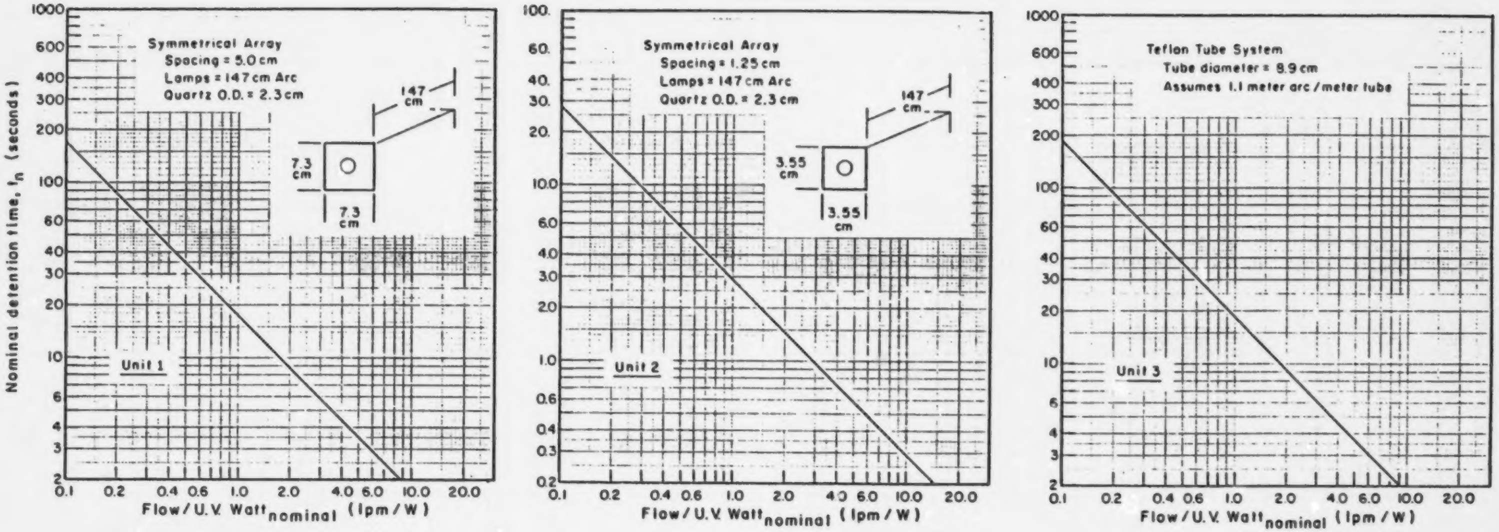


Figure 8-21. Nominal detention time as a function of loading rate for the three unit configurations.

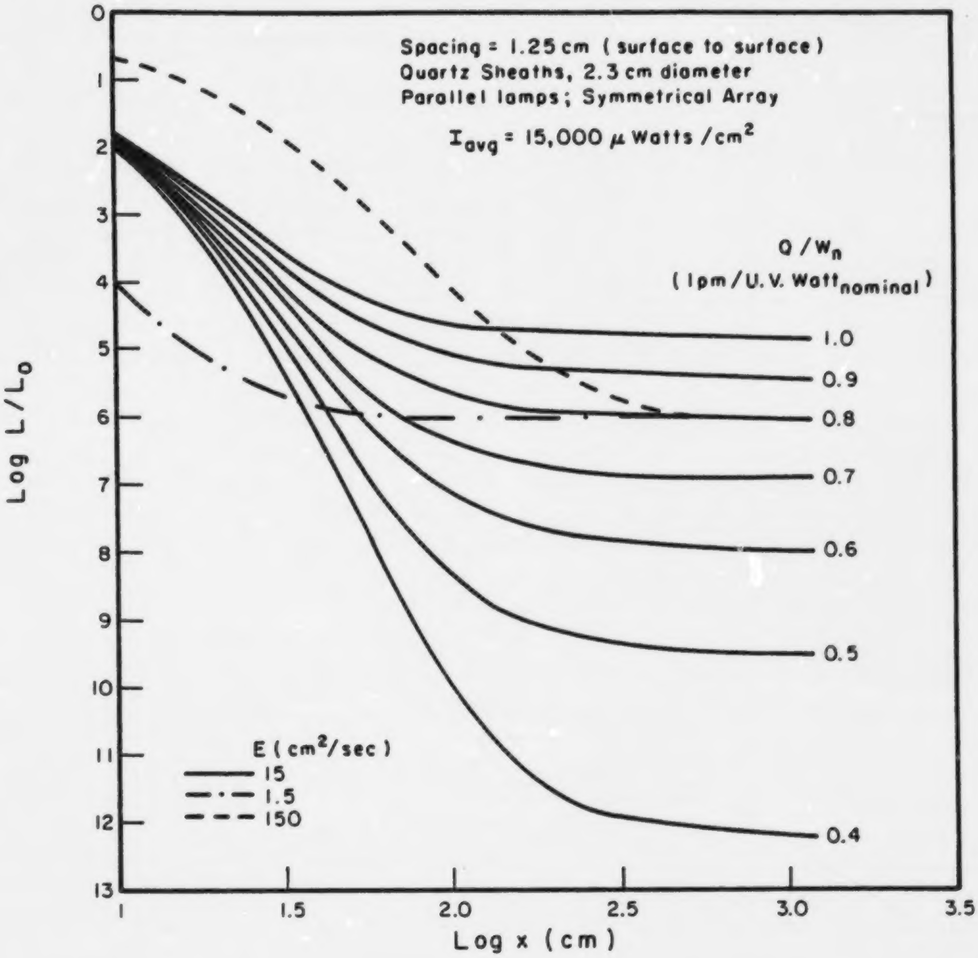


Figure 8-22. Model solutions for Unit 2 demonstrating performance as a function of loading and the dimension x.

$K = 0.0000145\ (15000)^{1.3} = 3.9\ \text{sec}^{-1}$

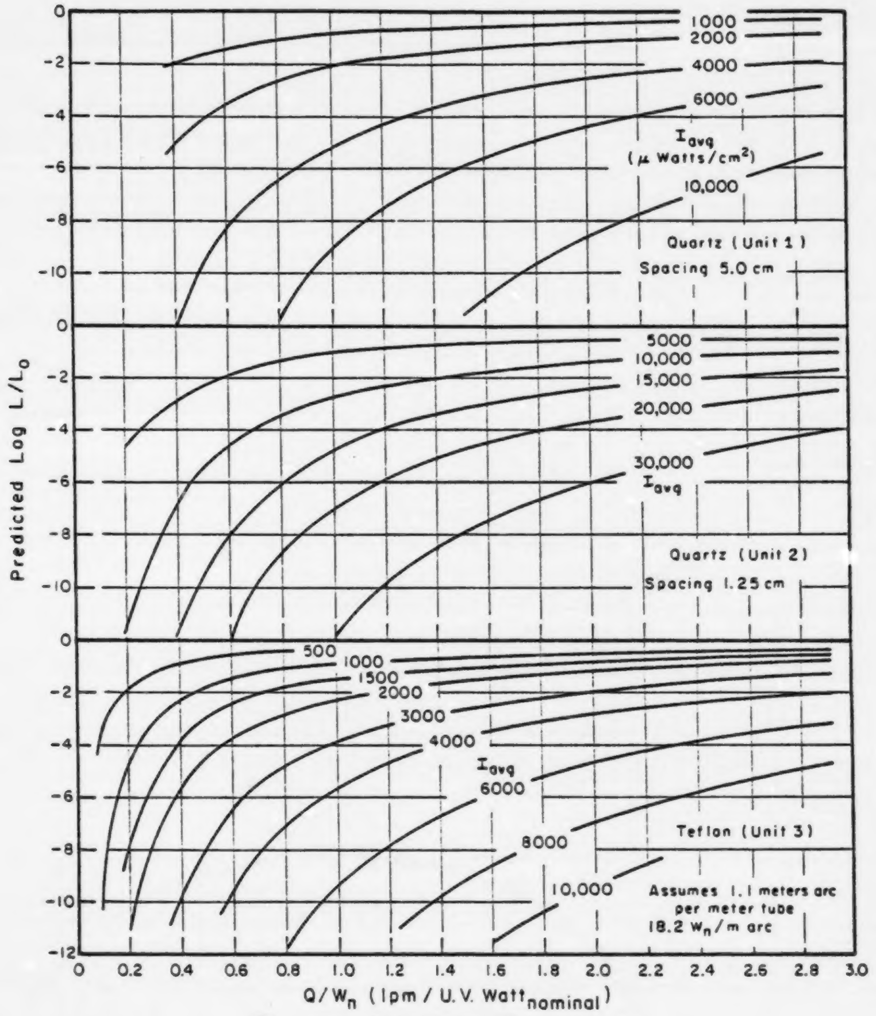
The dispersion coefficient, E, was set at a value of 15 cm^2/sec, and the model (Equation 8-15) was solved for L/L_o at different ratios of Q/W_n and values of x. The figure displays Log L/L_o as a function of Log x for a variety of loadings (Q/W_n). Two important notes to these calculations are highlighted at this time:

1. The term in Equation 8-15 which estimates the density associated with the particulates is not included in the model calculations. The value of $L_{particulate} = cSS^d$ would be additive to the solutions of the exponential term in the equation.

2. To work the model expression, the ratio Q/W_n is transformed to the corresponding time of exposure, t_n, using Equation 8.16. This time is then used to compute the velocity, u ($u = x/t_n$). If, by direct measure, the actual average detention time is known and is significantly different from the theoretical t_n, the actual time should be used in these computations.

Figure 8-22 clearly demonstrates the maximum Log L/L_o achievable at a given loading. As an example, for the given intensity of 15000 μWatts/cm^2, a Log L/L_o of approximately -6.0 can be achieved at a loading of 0.8 lpm/UV watt. Further, this will be achieved if the distance, x, is greater than approximately 200 cm (log x = 2.3) for a system with a dispersion coefficient, E, of 15 cm^2/sec. This minimum x can be reduced, as shown, if the E is 1.5 cm^2/sec; conversely, a far greater distance is required if the E is 150 cm^2/sec.

Figure 8-23 presents a series of solutions for each of the units in which the Log L/L_o is given as a function of the loading, Q/W_n, for a range of intensity levels. Again, $L_{particulate}$ is additive to these solutions. The solutions are also at values of x greater than $x_{minimum}$. These curves can be used to determine the maximum loading for sizing a system. Thus, as



(1) $L = L_0 \exp\left[\frac{ux}{2E}\left(1-\sqrt{1+\frac{4EaI^b}{u^2}}\right)\right]$

where $a = 0.0000145$ and $b = 1.3$

(2) L_{ss} would be additive.

(3) Assumes velocity is greater the minimum velocity.

Figure 8-23. Design solutions for 3 system configuration utilized at Port Richmond, showing performance as a function of loading and intensity.

an example, if Unit 1 is shown to have an intensity of 6000 μWatts/cm^2 and is required to achieve a Log L/L_o of -5.0, the maximum loading is 1.8 lpm/W_n.

Given the dispersion coefficient of the system, E, the minimum velocity of the system at that loading will be set. Figure 8-24 demonstrates the effect of the E on the minimum velocity for each of the three systems. The figure presents solutions at a given intensity and loading for each of the units; the log L/L_o is shown as a function of the log velocity for several different values of E. Recall that the velocity is computed as x/t_n, where t_n is a function of the ratio Q/W_n. For Unit 1, at a Q/W_n of 1.0, t_n is 17.5 seconds. At an intensity of 4000 μWatts/cm^2, the maximum Log L/L_o is approximately -5.2; as shown on Figure 8-24, the velocity at which this maximum Log L/L_o is achieved increases with increasing E. At an E of 1.5 cm^2/sec, the minimum velocity is 7.5 cm/sec (log velocity = 0.875), which, at a nominal exposure time of 17.5 seconds, is equivalent to a distance x of 131.5 cm. If the E were 15 cm^2/sec, the velocity would increase to 21 cm/sec. This would yield an x of 368 cm. Similar exercises can be made with the solutions shown on Figure 8-24 for Units 2 and 3.

It is important to note that for a particular unit configuration, the E will set the minimum velocity, regardless of the loading or the intensity. Given this fact, the relationship presented on Figure 8-25 can be constructed. The minimum velocity is presented as a function of the dispersion coefficient for each of the three units. This figure can then be used, once the maximum loading is established, to determine the minimum velocity necessary at the design condition. Thus, although the loading sets the number of lamps (i.e., the power) required for a particular system configuration, the velocity requirement determines the way the lamps should be arranged. As an example, it was noted that for Unit 1 to achieve a Log L/L_o of -5.2 at an intensity of 4000 μWatts/cm^2, the maximum loading would be 1.0 lpm/W_n. Additionally, if the E were 15 cm^2/sec, the minimum velocity was 21 cm/sec. Let us assume the design flow is 10000 lpm; at the loading of 1.0 lpm/W_n, this yields

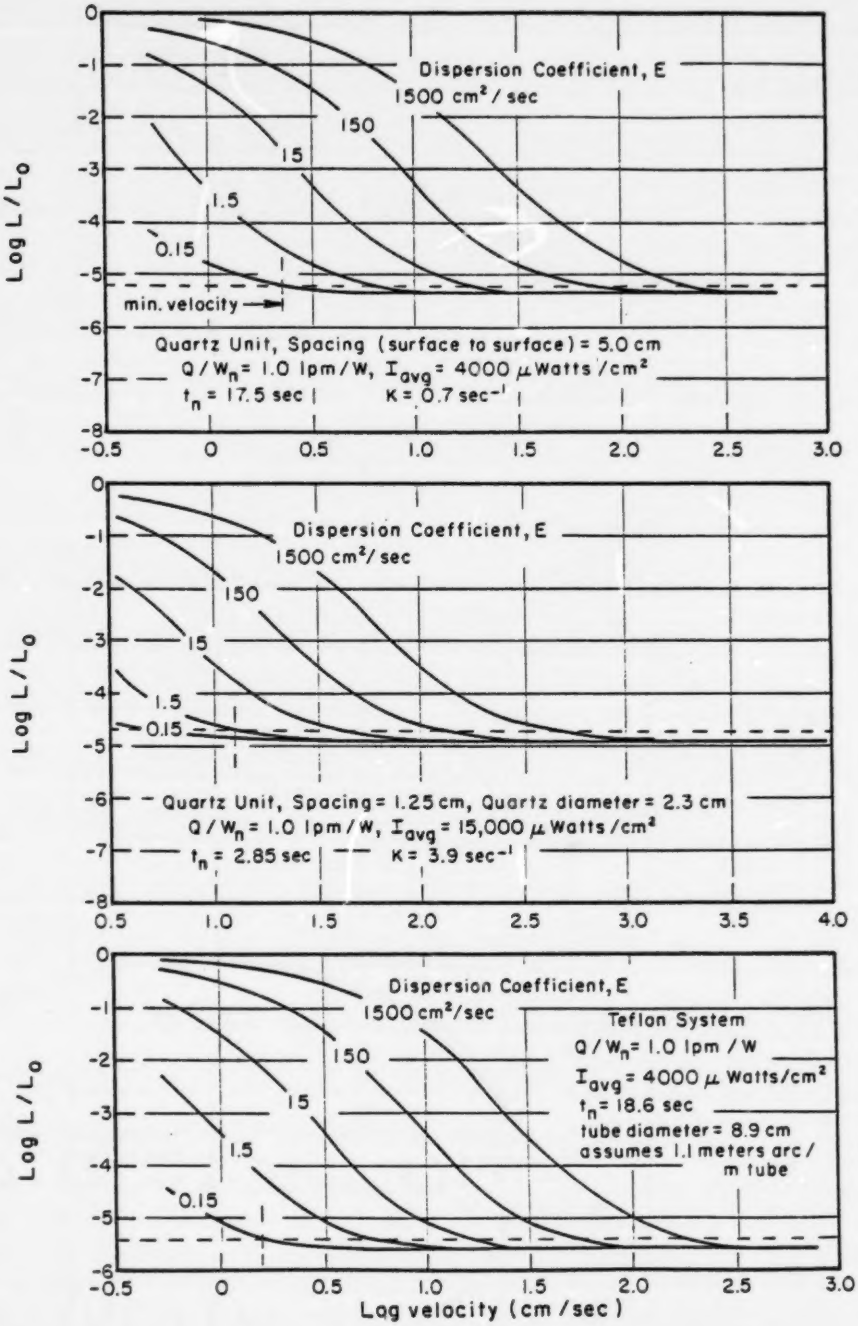


Figure 8-24. Model solutions for 3 Port Richmond design examples showing the effect of E on the minimum velocity required for a given loading and intensity.

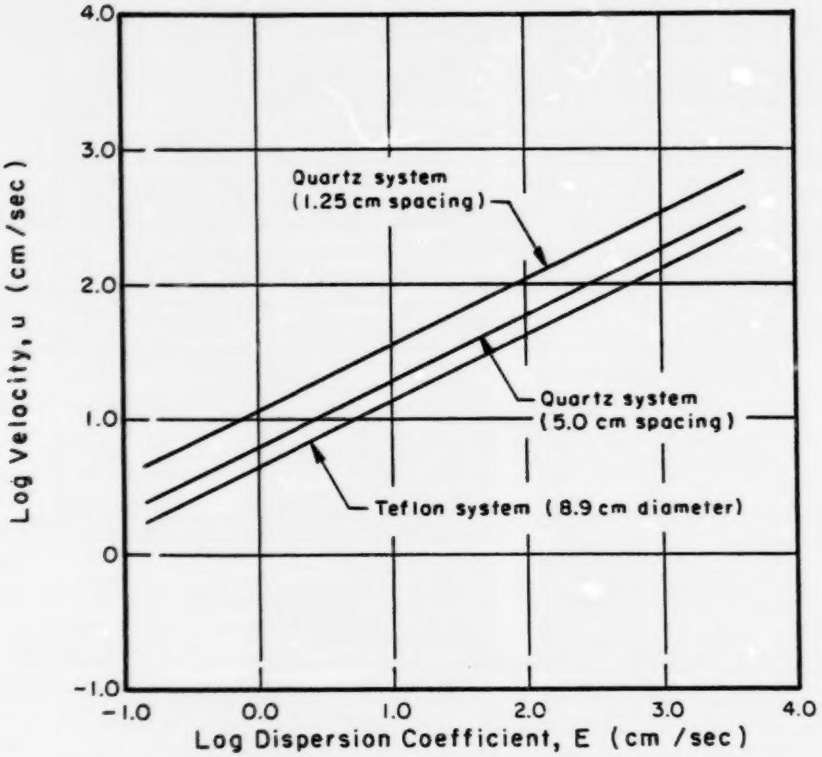


Figure 8-25. Model solutions showing the minimum velocity requirement as a function of the dispersion coefficient for the 3 Port Richmond system design examples.

10000 lpm/(1.0 lpm/W_n) = 10000 W_n

at a rated output of 18.2 Watts/m arc, the number of 1.47m arc lamps that would be required is,

(10000/ 18.2)/1.47 = 373

These lamps (with their 2.3 cm diameter quartz sheaths) are to be arranged in a symmetrical array with the centers spaced 7.3 cm both horizontally and vertically. The minimum velocity of 21 cm/sec will set the horizontal dimension in the direction of the flow:

t_n at a Q/W_n of 1.0 is 17.5 seconds;

$x = u(t_n) = 21 \times 17.5 = 367.5$ cm

Since 7.3 cm is associated with each lamp in the x direction, the number of lamps required in the x direction is

367.5 cm / 7.3 = 50.3 lamps

Rounding off in an appropriate fashion, the analysis shows that the unit should be arranged in an array of 7 lamps vertically and 54 lamps horizontally.

Application to the Port Richmond Plant

Consider the following design problem for the Port Richmond plant:

Peak daily flow = 315000 lpm (120 mgd)
Maximum 7-day average UV absorbance coefficient = 0.5 cm^{-1}
Maximum 7-day average suspended solids = 45 mg/1
Maximum 7-day effluent fecal coliforms (GM) = 7×10^5 FC/100ml

Determine the UV system requirements to achieve a maximum 7-day average fecal coliform density of 400 FC/100ml (geometric mean).

From an analysis of the Port Richmond pilot study data, it was determined that the fecal coliform density which could be attributed to the effluent suspended solids (after exposure) could be approximated by the expression,

$$L_{particulate} = 0.25\ SS^2$$

At the maximum 7-day average suspended solids of 45 mg/1, this yields an $L_{particulate}$ of 506 FC/100ml. This implies that the UV system would not meet its performance requirement under these wastewater conditions; one should understand, however, that the fecal coliform requirement is written as a geometric mean and the suspended solids average is an arithmetic mean. It is possible to have a mean fecal coliform density less than 400 (by the above expression) and still have an average suspended solids of 45 mg/l. As an example,

Suspended Solids (mg/l)	Estimated Fecal Coliforms (FC/100ml)	
70	1225	Log = 3.088
75	1406	3.148
30	225	2.352
20	100	2.000
25	156	2.194
60	900	2.954
35	306	2.48

The average of the suspended solids is 45 mg/l; the geometric mean of the estimated fecal coliform densities is 400 FC/100 ml.

It is appropriate then to continue the calculation on the presumption that UV will be effective in meeting the plant's effluent limitation. The design requirement, however, must be that complete kill is achieved in order to allow for the effect of the suspended solids. This implies that a Log L/L_o = −5.85 will be required, based on the estimated initial coliform density of $7x10^5$ FC/100 ml.

The next step is to determine the average intensity for each of the three system configurations:

From Figure 8-4, at an absorbance coefficient of 0.5 cm^{-1}, the $I_{average}$ for Unit 1 is 8400 μWatts/cm^2; for Unit 2 the intensity is 28600 μWatts/cm^2.

From Figure 8-8, at an absorbance coefficient of 0.5 cm^{-1}, the average intensity for Unit 3 is 4200 μWatts/cm^2. Note that this is for a tube which has six lamps surrounding it; a boundary tube (top and bottom tubes of a vertical row) would have approximately 80 percent of this intensity, or 3360 μWatts/cm^2.

These intensity estimates are based on 100 percent transmittance of the nomimal output of the lamps. The values must, therefore, be adjusted to account for the expected deterioration of the lamp output and for the losses incurred as the energy passes through the quartz and teflon envelopes. The following assumptions are made, based on the field experiences at Port Richmond:

1. The lamp output will be 75 percent of nominal. This implies an average operating age for the system lamp inventory of 4000 to 5000 hours. Such an assumption is appropriate since with time, a system will become (by intent) intermixed with newer and older lamps in order to maintain a desired overall average.

2. The average losses incurred by the quartz systems will be approximately 25 percent, implying a transmittance of 75 percent of the lamp output. This assumption is generally based on the experience at Port Richmond. The losses are intended to account for absorption by the quartz sheaths, and the fouling of the inner and outer surfaces of the quartz. Use of low ozone lamps (vycor) and sealing the quartz ends may allow a higher transmittance.

3. The transmissibility of the teflon tube is assumed to be 50 percent. This approximates the measured transmittance of the tubes utilized at Port Richmond after several months use (after having been cleaned).

The intensities for each unit can now be adjusted:

Unit 1: $I_{average} = 8400 \times 0.75 \times 0.75 = 4725\ \mu\text{Watts/cm}^2$

Unit 2: $I_{average} = 28600 \times 0.75 \times 0.75 = 16000\ \mu\text{Watts/cm}^2$

Unit 3: $I_{average} = 4200 \times 0.75 \times 0.5 = 1575\ \mu\text{Watts/cm}^2$

From Figure 8-23, the maximum loadings can be determined for each of the three units to achieve a Log L/L_o of -5.85 at their estimated intensities:

Unit 1: $Q/W_n = 0.96$ lpm/W_n
Unit 2: $Q/W_n = 0.89$ lpm/W_n
Unit 3. $Q/W_n = 0.29$ lpm/W_n

Earlier, the values of the dispersion coefficient had been set for each unit:

Unit 1: $E = 1.5$ cm^2/sec
Unit 2: $E = 15$ cm^2/sec
Unit 3: $E = 0.5$ cm^2/sec

From Figure 8-25 the minimum velocity can be determined. In turn, the minimum horizontal dimension, x, can be set utilizing the nominal exposure times derived from Figure 8-21:

Unit 1: $u = 7.9$ cm/sec; $t_n = 18$ seconds; $x = 142$ cm
Unit 2: $u = 43.6$ cm/sec; $t_n = 3.2$ seconds; $x = 140$ cm
Unit 3: $u = 3.16$ cm/sec; $t_n = 62$ seconds; $x = 196$ cm

The number of lamps (1.47 meter arc/lamp and 18.2 $\text{Watts}_{\text{nominal}}$/meter arc) can then be determined for the peak daily flow of 315000 lpm:

Unit 1: $W_n = 315000/(0.96 \text{ lpm}/W_n) = 328125$ watts
Lamps = 328125/(18.2 x 1.47) = 12264
Unit 2: $W_n = 315000/(0.89 \text{ lpm}/W_n) = 353932$ watts
Lamps = 353932/(18.2 x 1.47) = 13229
Unit 3: $W_n = 315000/(0.29 \text{ lpm}/W_n) = 1086200$ watts
Lamps = 1086200/(18.2 x 1.47) = 40599

Thus, the two quartz systems are effectively equivalent, while the teflon system requires approximately three times the number of lamps to achieve equivalent performance.

Given the required number of lamps and the minimum dimension in the direction of flow, an appropriate modular design can be determined for the particular plant design. Consider Unit 1, which requires 12264 lamps and a distance of at least 142 cm. At a spacing of 7.3 cm (between lamp centerlines) this distance translates to a requirement for at least 19.5, say 20 lamps, in the forward direction. If, as an example, the vertical height is also set at 20 lamps, then a minimum of 30 modules would be required (each with 20 x 20 = 400 lamps). This number of modules may be cumbersome and can be reduced by simply expanding the x dimension of the module. If the x distance were tripled and the vertical height kept at 20 lamps, then the module would be 20 lamps by 60 lamps, and a total of 10 would be required. Each module would effectively be arranged in three banks.

The above analysis considers the system requirements under peak or worst case conditions. This is, in effect, the equipment need for the full-scale design to meet all wastewater conditions and sets the capital requirement. Given the fact that the UV system is a modular design, one should consider the requirements as the plant approaches its design flow, and determine if the system can be phased in with time. Additionally, the O&M needs will be set by the average operations of the plant; this too can be evaluated at different time intervals in the plant's projected design life.

The system requirements under average operating conditions at the Port Richmond plant can be determined:

Average daily flow rate = 158000 lpm (60 mgd)
Average suspended solids = 15 mg/l
Average UV absorbance coefficient = 0.37 cm^{-1}
Average fecal coliform (GM) = 3.6×10^5 FC/100ml

These data (except for the flow rate) are drawn from Table 7-2 and represent the average of grab samples taken generally between the hours of 10 a.m. and 4 p.m. Thus they are representative of the normal period for monitoring disinfection performance.

The fecal coliform requirement under average conditions is that the maximum 30 day geometric mean not exceed 200 FC/100ml. This implies that on an annual average basis, the mean must be lower than the 200 level. For purposes of this design problem consider 100 FC/100ml to be the average performance goal for the UV systems.

The residual coliform density which will be associated with the effluent suspended solids can be approximated:

$$L_{particulate} = 0.25\ (15)^2 = 56\ FC/100ml$$

Since this is additive to the residual after exposure, the system design must yield an average Log L/L_o of approximately,

$$\mathrm{Log}\ L/L_o = \mathrm{Log}\ (100-56/3.6\mathrm{x}10^5) = -3.91$$

The intensities can again be estimated from Figures 8-4 and 8-8, applying the same reduction factors as discussed earlier:

Unit 1: $I_{average} = 13500 \times 0.75 \times 0.75 = 7600\ \mu Watts/cm^2$
Unit 2: $I_{average} = 36500 \times 0.75 \times 0.75 = 20500\ \mu Watts/cm^2$
Unit 3: $I_{average} = 6250 \times 0.75 \times 0.5 = 2340\ \mu Watts/cm^2$

Given these estimates Figure 8-21 can be used to determine the maximum loading allowable to yield a Log $L/L_o = -3.91$:

Unit 1: $Q/W_n = 2.7$ lpm/UV watt
Unit 2: $Q/W_n = 2.6$ lpm/UV watt
Unit 3: $Q/W_n = 0.75$ lpm/UV watt

The same dispersion coefficients are assumed to apply in the average loading case; thus, the minimum velocities are the same. These can then be used in conjunction with the nominal exposure times (Figure 8-19) to determine the minimum dimension x:

Unit 1: $u = 7.9$ cm/sec; $t_n = 6.6$ seconds; $x = 52$ cm

Unit 2: $u = 43.6$ cm/sec; $t_n = 1.2$ seconds; $x = 52$ cm

Unit 3: $u = 3.16$ cm/sec; $t_n = 25$ seconds; $x = 79$ cm

The number of lamps required at the average daily flow of 158,000 lpm can be estimated:

Unit 1: $W_n = (158000/2.7) = 58518$ watts

Lamps $= (58518)/(18.2 \times 1.47) = 2187$

Unit 2: $W_n = (158000/2.6) = 60769$ watts

Lamps $= (60769)/(18.2 \times 1.47) = 2271$

Unit 3: $W_n = (158000/0.75) = 210666$ watts

Lamps $= (210666)/(18.2 \times 1.47) = 7874$

These represent significant decreases in system requirements from those computed for the peak conditions for the Port Richmond plant. The UV systems, although capital intensive to meet maximum demand, are reasonably efficient in meeting performance requirements for the average operation at the plant. This analysis also clearly points to the benefits of closely controlling the system to meet current demands. Knowledge of the current lamp status and the quality of the effluent can be effectively applied to keep the system loading at its maximum allowable. This will allow the most efficient utilization of the lamps and the power required to run them.

SECTION 9

SUMMARY DISCUSSION OF UV SYSTEM DESIGN CONSIDERATIONS

PROCESS DESIGN PROTOCOL FOR THE APPLICATION OF UV DISINFECTION

The discussions presented in Section 8 demonstrate the utility and effectiveness of the UV model for both process design purposes and for controlling the system operation for maximum efficiency. The model, when calibrated to data corresponding directly to the wastewater conditions being considered, is found to correctly respond to changes in process design parameters and to yield effective insight into the sensitivity of the system design and operation to these parameters. As such, it is proposed that the modeling protocol, in conjunction with the collection of the appropriate in-field information, be utilized for the design and operation of full-scale systems.

Wastewater Characteristics

Certainly a major element in the effective design of the UV disinfection system is a clear and concise understanding of the characteristics of the wastewater to be treated. These will be directly related to degree of pretreatment the material will receive before the disinfection step and will certainly affect the sizing and performance of the disinfection system. Pretreatment will range from very minimal, as in the case of combined sewer overflows and primary effluents, to very high quality, as in the case of advanced tertiary plants. Typically, the wastewater will result from secondary and advanced secondary treatment facilities.

The information which will be important to the design and operation of a UV disinfection system may be summarized as follows:

1. Wastewater flow rates. These estimates should be for the design year of the plant. There should also be some knowledge of the progressive increase in the flows through the design life of the plant in order to determine if the system can be phased in by the addition of modules as the demand increases. Some consideration should also be given to the hydraulic equalization provided by the plant in determining the peak hydraulic load to the unit. The flow rates important to the design and evaluation of the system are those typically considered for wastewater treatment systems:

   Annual average daily flow
   Average wet weather flow
   Average dry weather flow
   Maximum 7-day average flow
   Maximum 30-day average flow
   Peak daily flow
   Peak hourly flow

2. The absorbance characteristics of the wastewater at the 253.7 nm wavelength. This is best described by the UV absorbance coefficient as used in the context of this report. It will affect the intensity of energy which can be achieved by a particular unit configuration. The best measure of absorbance is one which corrects for scattering, such as with the integrating sphere used at Port Richmond. Alternatively, the direct spectrophotometric measurement of a filtered sample was found to be an adequate approximation of the spherical (corrected for scatter) absorbance coefficient.

   The daily average, maximum 7-day, and the maximum 30-day average UV absorbance coefficient would be important. Unlike the suspended solids, which is limited by permit and by the treatment process, the UV absorbance coefficient is not a parameter describing treatment goals. It is an artifact of the wastewater and the treatment of that wastewater. Thus, an estimate will have to be made of the UV absorbance coefficient, and its variability, either by direct measure of the treated wastewater (as in the case of an existing plant) or a similar wastewater undergoing the same degree of treatment.

Strong correlations were not found between the UV absorbance coefficient and other more common parameters of water quality such as COD or TOC. These parameters may be useful, however, in assessing the variability in the quality of the wastewater, which can then be extrapolated to the expected variability of the UV absorbance coefficient.

3. Initial Coliform Density. As indicated by the formulation of the mathematical expression for disinfection, the performance (i.e., the residual density) achievable by a given system is directly related to the initial density. This density, in turn, will vary from plant to plant and will reflect to some degree the type of treatment system and the retention time in the plant. The greater the degree of treatment the lower the density will be; additionally, the greater the detention time the lower the coliform density will be in the plant effluent (e.g., a high rate versus an extended aeration activated sludge plant). These data should be generated for the particular plant in question or for a similar treatment plant handling a wastewater of similar characteristics. The variability of the effluent density should also be clearly understood.

4. Suspended Solids. The particulates have been demonstrated to play a potentially significant role in the residual densities achievable by the UV process. Coliforms occluded by the particles will be protected to some degree from UV radiation and will not be inactivated. The two common indices of the particulates in wastewater are the suspended solids concentration and the turbidity; the suspended solids is the most common and is typically written into permit limits for treatment plant discharges. The Port Richmond data indicated that the coliforms associated with the suspended solids were significant and could affect the sizing of a UV system, as demonstrated by the design examples presented in this section.

As with the initial coliform density levels, the density associated with the effluent solids will be related to the type of treatment plant and the solids retention time in the plant. It will be important to understand the variability in the effluent solids; generally the maximum 7-day and 30-day averages will be set by the permit conditions. This in turn will imply an average suspended solids to be achieved by the plant's process operations. As an example, for a plant to meet a maximum 30-day average of 30 mg/l, it is typically necessary that it maintain an annual daily average suspended solids level of approximately 15 to 20 mg/l.

In summary, the parameters of primary concern regarding the characteristics of the wastewater are the flow rate, UV absorbance coefficient, suspended solids, and initial coliform density. The peak design condition for a plant should not necessarily consider the concurrent occurrence of these parameters as the worst case condition. If sufficient data are available, running averages of combinations of these parameters should be constructed to determine the maximum 7-day and 30-day average of the combined parameter set. Thus, the maximum 7-day coliform density may occur under average flow conditions, as an example. Analysis of the data in this fashion may allow a more realistic system sizing to achieve the desired performance under the anticipated worst case condition.

Determination of the Coefficients Describing the Sensitivity of the Wastewater to UV Disinfection

Calibration of the model requires direct determination of the inactivation rate as a function of the intensity and an estimate of the residual coliform density associated with the suspended solids. These are the coefficients a, b, c, and d in Equation 8-15. They will be site specific and will need to be determined experimentally. As more field experience is gained with the application of UV these coefficients may be found to cluster about certain levels relative to the type of wastewater and the degree of treatment. These may be used as approximations for first cut design estimates; it is strongly recommended, however, that direct piloting be conducted to verify and or refine these estimates.

The piloting need be directed only at the data which are necessary for the model calibration. Demonstration of long term performance at a given loading or an evaluation of O&M needs over time are not issues which can be effectively resolved by piloting. These elements of a system evaluation are best answered by observation of existing full-scale facilities and the experiences of engineers and operators directly involved in their design and operation.

The pilot studies should incorporate the ability to obtain data at two significantly different intensity levels. This may best be accomplished by using two units which differ in lamp spacing, as had been done at Port Richmond. The sizing of the systems does not need to be large, although it is recommended that the units should have ten lamps (0.75 meter arc lamps would be sufficient) at minimum. There are no restrictions on the configuration of the lamps relative to flow (e.g., parallel or perpendicular), or in the arrangement of the lamp array (the lamps should be parallel to one another, however).

The wastewater effluent should be piped to the unit and there should be the capability to vary the flow rate. Flow rates must be accurately measured. The sampling and analyses will center on measurement of the influent and effluent bacterial density (typically, this will be total and/or fecal coliforms), the UV absorbance coefficient, and the suspended solids.

The pilot unit lamp configuration would first require evaluation by the point source summation method to calculate the intensity in the unit as a function of the UV absorbance coefficient. This would be similar to the relationships presented on Figures 8-4 and 8-8. During the term of the pilot study, direct measurements would be required to determine the output of the units' lamps and the transmissibility of the quartz and/or teflon enclosures. These tasks can be accomplished by the methods described in Sections 5 and 7. The information on lamp output and transmissibility would be used to adjust the calculated intensities. The adjusted intensity would also correspond to the UV absorbance coefficient measured at the time of sampling.

The hydraulic characteristics of the pilot units would then have to be defined directly by running tracer analyses. The procedure for the derivative method was described in Section 5; the analysis of the data was presented in Section 7. The required information would be an estimate of the dispersion coefficient, E, and an estimate of the actual detention time (mean) versus the theoretical detention time. If the mean detention time is significantly different from the theoretical detention time, then this measured value should be used in the model expression.

Determination of the Residual Bacterial Density Associated with the Effluent Suspended Solids--

The procedure for evaluating this parameter was discussed earlier in this section with regard to the Port Richmond data. Samples are analyzed at very high dose levels in the pilot units (high exposure times); the premise is that the residual density measured after such a high apparent dose is attributable to the bacteria being protected by occlusion in the suspended solids. Linear regression analyses of the log effluent residual coliform density as a function of the log of the effluent suspended solids will yield the coefficients c (intercept) and d (slope). It is important to evaluate the units in this fashion over a significant range of suspended solids concentrations. It may be necessary to artificially adjust the wastewater to accommodate this requirement.

Determination of the Inactivation Rate as a Function of the Calculated Intensity--

Influent and effluent data should be collected at flow rates which are high, yielding low "apparent" doses. The intent is to determine the rate of inactivation; this requires that the exposure time be sufficiently low to allow significant bacterial density levels in the effluent. The rate, K, is then determined by solution of the model expression. The procedure for this was explained in detail earlier in this section. A linear regression analysis of the log K as a function of the log intensity will then yield the intercept and slope, which are the coefficients a and b, respectively.

UV System Design Considerations

Once the disinfection model has been calibrated by incorporation of the coefficients a, b, c, and d, a matrix of system configurations can be evaluated. The design variables now become the intensity in the system and the hydraulic characteristics of the system.

Intensity--

The intensity of a particular lamp configuration will be a direct function of the spacing between lamps, the output of the lamps, and the effective transmission of the energy into the liquid. The suggested approach for determining the average intensity is by calculation, using the point source summation method. Solutions such as those presented on Figures 8-4 and 8-8 can be constructed for any number of unit configurations. The best approach is to construct these on the basis that the lamp (typically the low pressure mercury arc lamp) is at 100 percent output and that there is 100 percent transmission to the liquid through whatever envelope is shielding the lamp from the liquid (e.g., teflon or quartz). In this fashion the variants in the calculation are limited to the cross-sectional dimensions of the lamp battery, the rated output of the UV source, the UV absorbance coefficient of the liquid, and the dimensions of the enclosures (the standard quartz sleeves are typically 2.3 cm in diameter, as an example).

Once the intensity versus absorbance coefficient has been determined, the subsequent evaluations can center on the sensitivity to the energy losses which can occur within the system (this is also a very useful tool for monitoring and optimizing the operations of a particular system). These losses will be due to the deterioration in lamp output and to the absorbance by the quartz or teflon envelopes. The lamp output will naturally decrease with cumulative operating time. The absorbance by the quartz or teflon tubes will generally be at a given value when new, but will increase as the material ages and/or becomes dirty. The discussions in Section 7, including the data presented on Figures 7-18 and 7-19, clearly demonstrate the impact of these conditions. The estimated losses can be incorporated into the intensity estimates by directly factoring the loss against the estimated $I_{average}$ at 100 percent output and transmissibility. This was demonstrated in the examples provided earlier.

Hydraulic Design Considerations--

At a given intensity level, there will be a given loading, Q/W_n, to achieve a desired performance (Log L/L_o). This was demonstrated by the solutions presented on Figure 8-22, and subsequently on Figure 8-23. This loading is simply an alternative way of presenting the UV dose (intensity times time), since the Q/W_n implies a nominal exposure time for a given lamp configuration (see Figure 8-21). But, as was demonstrated by Figures 8-24 and 8-25, the hydraulic characteristics of the unit will influence how the lamps are arrayed. If the unit will have a high degree of dispersion (or the possibility of significant short-circuiting) the lamp battery should be configured to allow a long travel distance and higher velocities. This, in turn must be reconciled with the headlosses which can be tolerated by the specific plant design. The higher the aspect ratio (length to width) and the higher the velocity, the higher the headloss will be.

The major consideration in attempting to minimize the dispersion and/or short-circuiting within the lamp reactor is to assure the proper fluid approach to and exit from the lamp battery. The ideal condition is to have equal velocities across the plane of the lamp battery on both the inlet and outlet sides. In situations where the wastewater is piped to and from the UV reactor the higher pipe velocities must be dissipated and the flow must be evenly distributed across the plane of the lamp battery. Recall that this was the situation with the two quartz systems at Port Richmond. The piped inlet and outlet of the reactor created higher velocities through the middle of the unit. This was resolved by installing overflow wiers both before and after the lamps to distribute the flow across the unit. Additionally, a stilling plate was installed in front of the lamps to assure an even distribution of flow both horizontally and vertically.

System Design

Given the protocol presented above, the disinfection model can then be used to determine the optimum design for a given application. The model approach allows the testing of several design scenarios and any number of unit configurations. At minimum, it allows the designer to evaluate directly the systems proposed by a manufacturer, in a fashion similar to the three design examples presented earlier for the Port Richmond plant.

DESIGN CONSIDERATIONS FOR EFFECTIVE OPERATION AND MAINTENANCE

The discussions which have been presented in this section and in Section 8 have related primarily to the protocals necessary for the successful process design of a UV system. The intent is to design a system which will achieve the required performance, as defined by its disinfection efficiency, in the most efficient and cost-effective manner. As important as this may be, it is equally important to design the system in such a way as to allow effective operation and maintenance of the system. Design deficiencies in this area will cause increased operating costs at best, at worst they can cause a deterioration in the performance of the system, eventually leading to failure of the process.

A number of observations are presented, which are meant to provide some guidance in designing a UV disinfection system which will be effective in regard to O&M. Such a design should acknowledge the value of operator labor, and should minimize the frustration which can be fostered by a poorly designed and/or fabricated system. The reader has also referred to the discussions in Section 7 regarding the operations of the units during the Port Richmond field study.

Total System and Housing Considerations

It is recommended that the UV system be housed in an appropriate building. Depending on the size of the disinfection systems and the general layout of the plant, this may be a building specifically for the disinfection process or one which houses several unit operations. The design of the building should address several considerations with regard to the UV process:

- Give adequate area to the UV system. In addition to the requirements of the system itself, there should be enough work area for the removal and handling of the system components (lamps, quartz, etc.). The building should not house other operations which may cause excessive vibration.

- The ability to add modules should be considered in the design of the building. This would require added building space and the ability to move the equipment in and out of the structure.

- The building should contain a protected area for the storage of an adequate inventory of replacement parts for the UV systems. This would include lamps, quartz (or teflon tubes), ballasts, and other critical replacement parts.

- The building design should consider the maintenance tasks associated with the UV systems and the special monitoring efforts they require. There should be adequate room for measuring specific components outside the unit (lamp output, quartz transmissibility, etc.). The requirements for chemical cleaning should be understood; a separate area for chemical storage should be provided and there should be adequate drainage provided for the units and for the general area.

- The building should be adequately ventilated. The humidity in the building should also be kept at reasonable levels.

UV Reactors

The basic design and fabrication of the reactors will vary from manufacturer to manufacturer. The basic design intent is to provide a system which will efficiently deliver the UV radiation to the wastewater for the required amount of time. Certainly, this can be accomplished in a number of ways and the accessory equipment provided with the system can also vary widely from minimal to the ability for full automation. The following suggestions are made for the designer to consider when evaluating the equipment proposed for a particular installation:

- The wastewater approach and exit design should encourage a plug flow condition, with minimal loss of effective volume. There should be no degree of direct short-circuiting. The design should allow an effective and even distribution of flow (velocity) across the entire plane of the lamp battery.

- In multiple system designs, there should be adequate fexibility in directing flow. Screening should be provided at the headend of the UV systems to minimize any damage from debris which may enter upstream of the system. The screens should be removable for maintenance, and accessible.

- In cases where tanks are provided for the influent and effluent portions of the system, they should be of adequate size to allow good hydraulic conditions and good access to the lamp battery. There should be adequate drainage of the tanks and the reactor.

- It is critical to the O&M of a system that the key components of a unit be as fully accessible as is practical. This applies to the lamp battery itself and to the power supply. The lamp battery should be built in a manner such that it can be easily inspected and the lamps and quartz/teflon enclosures are easily removed. Sealed reactor shells, if used, should have manways built in; this would allow inspection of the interior of the unit (when drained). The power supply should be remote from the lamp battery; again the ballasts should be accessible and easily removed and replaced.

- Greater attention should be paid to designing a system which allows for efficient removal of the lamps, quartz sleeves, and teflon tubes.

It would encourage a greater degree of effective maintenance and monitoring of the lamps and enclosures if they were more accessible than current designs allow. As an example, if stacking of the teflon tubes is a necessary part of a unit design, attention should be paid to how the bottom tubes can be reached and/or removed without having to dismantle all tubes and lamps above it.

Power Supply

The power supply to the UV systems should be remote from the reactors. Additionally, it may be useful to install a power meter to monitor the power consumption by the disinfection system itself. The power panel should be installed at a level above the reactors to reduce the danger of electrical hazards in the event of a reactor failure and flooding. It is suggested that the control and monitoring instrumentation be installed separate from the power panel. The heat generated by the ballasts, if not adequately controlled, can cause damage, not only to the ballasts, but to other components installed in the power panel.

The critical element in the proper assembly of the power supply for the reactors is the proper mating of the ballast to the lamp. It is not appropriate to suggest which combinations are proper for a given installation. The designer is strongly encouraged to approach both the lamp and ballast manufacturers to confirm the appropriate use and matching of the two components. The UV equipment suppliers should also be asked to supply the names of other installations which use the same lamp/ballast combination.

The ballasts will generate heat; it is important that thermally protected ballasts be installed to prevent the loss of the ballast. It is equally important to provide for adequate ventilation of the heat generated by the ballasts. This can be accomplished by the installation of high volume fans in the power panel. The temperature in the panel should also be continuously monitored and alarms installed to alert the operator of excessive heat buildup. The designer may also wish to consider using this excess heat during cold temperature months as a supplement to the building's main heat system.

Monitoring and Control Systems

There are advantages to installing a system in which one can control the energy input as a function of the current energy requirement. The total energy consumption and the rate of lamp utilization can be reduced by doing this. These two components comprise the major share of the O&M costs for UV disinfection (as is discussed in Section 10). The current energy requirement will be a function of the wastewater quality and its flow. The system will have to be monitored for these components and there would have to be a control system to correspondingly operate the appropriate number of lamps.

The operation of the UV system can be slaved to the flow rate and/or the quality of the water. The number of lamps or the actual energy required will have been determined; this is to meet specific performance goals (e.g., log survival ratios, or residuals densities). Recall that the mathematical modelling approach discussed earlier would allow for setting operating guidelines under varying water quality and flow combinations.

Monitoring the quality of water should be accomplished by the direct measurement of the UV absorbance of the liquid. This can be done by manual sampling and measurement by a UV spectrophotometer and/or continuously by an in-line monitor of UV absorbance, similar to the instrument utilized for the Port Richmond study (see Section 7). A continuous in-line monitor would allow dual slaving of the system to both wastewater flow rate and to the UV absorbance of the water.

In place UV intensity meters are installed with most systems; their utility is limited and will be a direct function of the level of maintenance given to keeping them clean and properly calibrated. They are also limited to monitoring the relative output from only those lamps within a few centimeters, and will not signal problems which may occur in other portions of the unit. To offset this problem, several detectors would have to be placed in the unit. The intensity meters should be used only as a short term monitor for the cleanliness of the quartz and teflon tubes. This task may best be handled, however, by draining the unit and visually inspecting the surfaces.

Controlling the level of energy delivered to the system can be done by either turning lamps on and off or by varying the voltage to the lamps. In either case the operating range should be relatively insensitive to small changes in flow rate or water quality. Frequent adjustments should be avoided; this will only decrease the life of the lamp.

Other system monitors which would be useful to the proper O&M of the system would include:

- Temperature of the lamps. This is not a simple measurement since the lamp skin temperature will vary along its surface and it is difficult to obtain a true lamp skin measurement. It would be appropriate, however, to at least monitor temperature at one point and to relate this to actual lamp skin conditions. Excessive deviation from the normal operating temperature can then be monitored; adjustments in the number of lamps operating can then be made to compensate for the loss of output at these temperature extremes.

- Individual lamp operating display. Typically this is accomplished by LEDs or fiber optics. This allows for the direct monitoring of the lamps and the actual number of operating lamps. Alarms should also be installed to signal excessive lamp outages.

- Cumulative elapsed time clocks should monitor the operating time for each individual bank of lamps comprising the system. This, in conjunction with the direct monitoring of each lamp, can be used to monitor lamp age.

System Maintenance

The major maintenance tasks associated with the UV systems which should be considered in the equipment design may be summarized as follows. These observations are based on the experiences with the Port Richmond study:

- Instrumentation calibrations, lubrication, and repairs. Not unlike the requirements in other unit operations at a treatment plant, proper maintenance of the control and monitoring instrumentation is important. The degree of sophistication should not be high; in fact, except on very large systems it is generally not cost-effective to install automatic control systems.

- Lamp and lamp enclosure inspection and cleaning. To accomplish these tasks it is important to have the ability to bypass and shutdown individual modules, without having to halt the disinfection process. The unit should be easily and quickly drained; there should also be the ability to visually inspect the lamp battery once the unit is drained. If the lamp battery requires cleaning, the system design should allow the ability to quickly inject a cleaning solution into the reactor and provide agitation as the solution contacts the surfaces. In some cases it is necessary to physically rub the surfaces in order to remove the fouling material. Additionally there may be a need to apply both an acid to remove inorganic scale, and a detergent to remove grime and grease.

- The system should be completely overhauled at least once per year to clean all surfaces and to monitor the lamps for relative output and the quartz or teflon for relative transmittance. The procedures for doing this have been discussed in Section 7; they are felt to be important for effective operation of the system. The design of a system should recognize the need for this task and make the disassembly of the unit as easy and practical as is possible. An accessory to the system would be an arrangement by which the lamps and quartz can be individually monitored for output and transmissibility with a UV radiometer.

SECTION 10

COST ANALYSIS FOR UV DISINFECTION

INTRODUCTION

A cost analysis was conducted to estimate the capital and the operational and maintenance costs associated with UV disinfection. These estimates are based on the results of this study, and equipment costs provided by a number of manufacturers. It is very important for the reader to understand that these costs are screening estimates; the actual costs will be very sensitive to the site, the equipment to be used and its installation requirements, and the performance required for the given wastewater characteristics. The estimates provided herein are intended to give a reasonable approximation of the cost which would be incurred if UV were to be installed. They are normalized to the size of the UV system on the basis of total killowatts; thus, the system must first be sized for the specific site and wastewater characteristics. The protocols for determining the process design were discussed in Section 9. The costs derived in this section would be adequate for use in comparing against the costs estimated for alternative systems. The user should make every attempt to modify these estimates to incorporate what is known about the specific site installation and the requirements of the individual manufacturers.

Capital Costs

The capital costs are divided to two specific areas: equipment and installation. The equipment elements include the hardware requirements directly associated with the installation of the UV process. The installation elements are those concerned with the hookups and physical plant needs to install the system at a specific site.

Equipment Costs--

Four major UV equipment manufacturers provided information on the hardware costs of their equipment. They were asked to provide base costs for the UV system itself and added costs for the ancillary equipment used to control or monitor the system. The estimates in all cases were normalized to the total power draw of the system; this was calculated by multiplying the number of lamps by the nominal power rating of the lamp. The costs for the total equipment package are presented on Figure 10-1. These costs include:

- Base UV lamp battery (UV reactor).
- Power supply and power panels (with single point hookup to the plant power).
- Instrumentation for the control and monitoring of the system. This includes a UV intensity monitor per module, pilot monitors for each lamp, controller to direct the number of lamp banks on as a function of flow (and/or water quality), and alarms to signal deficiencies in lamp operation and/or performance.
- Accessory cleaning equipment. This is generally in the form of chemical cleaning, mechanical wipers, or ultrasonics.
- Manufacturer's engineering and startup costs.
- Replacement parts supplied with purchase. This includes 100 percent lamps, 50 percent ballasts, and 20 percent quartz or teflon tubes.

The line drawn on the figure represents the average of the manufacturers' costs at each of the power size levels which had been requested. At the lower level, for a 1.6 kW system (20 lamps), the average equipment cost was $11,500. The costs ranged between 30 percent below the average to approximately 40 percent above the average. The estimates drew closer for the larger systems; at the 16 kW level (200 lamps) the average was $83,000

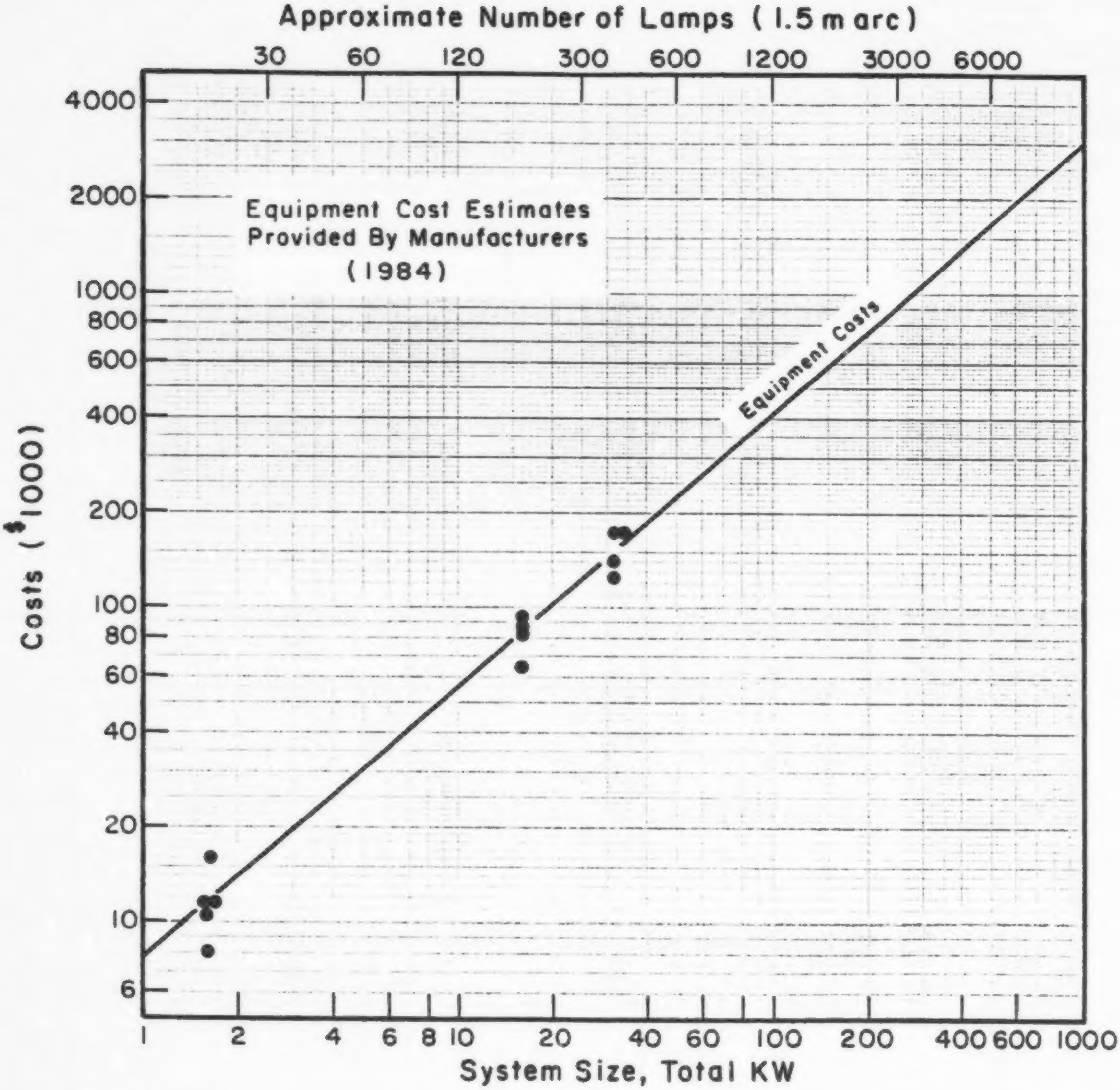


Figure 10-1. Costs of UV equipment as a function of the total power of the system.

with a range of -30 to +12 percent; at the 32 kW level (400 lamps), the average was $152,400, with a range of -17 to +15 percent.

The costs were not clear in all cases when attempting to break out the costs associated with the ancillary equipment. From the limited information which had been provided it is estimated that approximately 15 to 25 percent of the total cost involves the monitoring, cleaning, and control systems provided with the base reactor. Similarly, 15 to 25 percent of the total costs are associated with the replacement parts purchased with the original equipment.

Installation Costs--

Clearly, the cost aspect which is most sensitive to the specifics of the site and the equipment to be installed is the structural and installation requirements. It is very difficult to give an accurate cost estimate for these elements of the system; for the sake of discussion, however, a generic installation will be considered. The assumptions which were used may be summarized as follows:

- There will be a basic space requirement for the UV system at a plant, based on the number of lamp modules to be installed. The smallest plants would only require one module; the reactor itself will be rather small. A minimum space of 10 m^2 should be allowed, however, for the unit. This space allocation is increased to 25 m^2 for large modules which may contain several hundred lamps. Thus, a 500 kW system may contain approximately 6000 lamps in 10 modules; the total space allocation would be approximately 250 meters squared. In order to estimate the costs for the physical structures associated with this requirement, it was assumed that the system would be housed in a standard building. Certain configurations proposed by engineers/manufacturers (including existing full-scale systems) do not require such housing. The designs in this case generally call for open channel installations of the UV equipment. The power supplies and instrumentation in this case require more stringent specifications with regard to weatherproofing and protection against water/electrical hazards.

Reactors which are housed are generally characterized by piped inlet and outlet structures. The reactors are typically sealed units or have integral influent and effluent tanks attached to the lamp battery. The housing itself may be shared with other unit operations in the plant. Power supplies and control systems are contained in the building, typically remote and elevated from the reactors. Storage for spare parts (lamps, ballasts, etc.) can also be accomplished within the building.

A unit cost of $800 per square meter is assumed for the structural costs associated with the UV system building space. These costs include the foundation, walls (standard block), floor, roof (4 meter clearance), site work, heating, ventilation, and lighting.

- Installation costs are estimated at 20 percent of the total equipment costs. This includes the electrical service, equipment installation and connection, utilities, instrumentation, and building connections.

- Engineering and related costs are assumed to be approximately 10 percent of the costs associated with the structural and installation requirements.

- A contingency of 25 percent of the structural costs is allowed for the total system.

Total Capital Costs--

Figure 10-2 presents the total capital costs estimated for the installation of a UV disinfection system. The equipment and installation costs which make up this total are also presented on the figure. An example of the calculations is presented for a 50 kW system to demonstrate how the curves on Figure 10-2 were developed.

Total system power = 50 kW
Total number of lamps (at approximately 80 watts per lamp) = 600
Number of reactor modules = 3 (200 lamps per module)

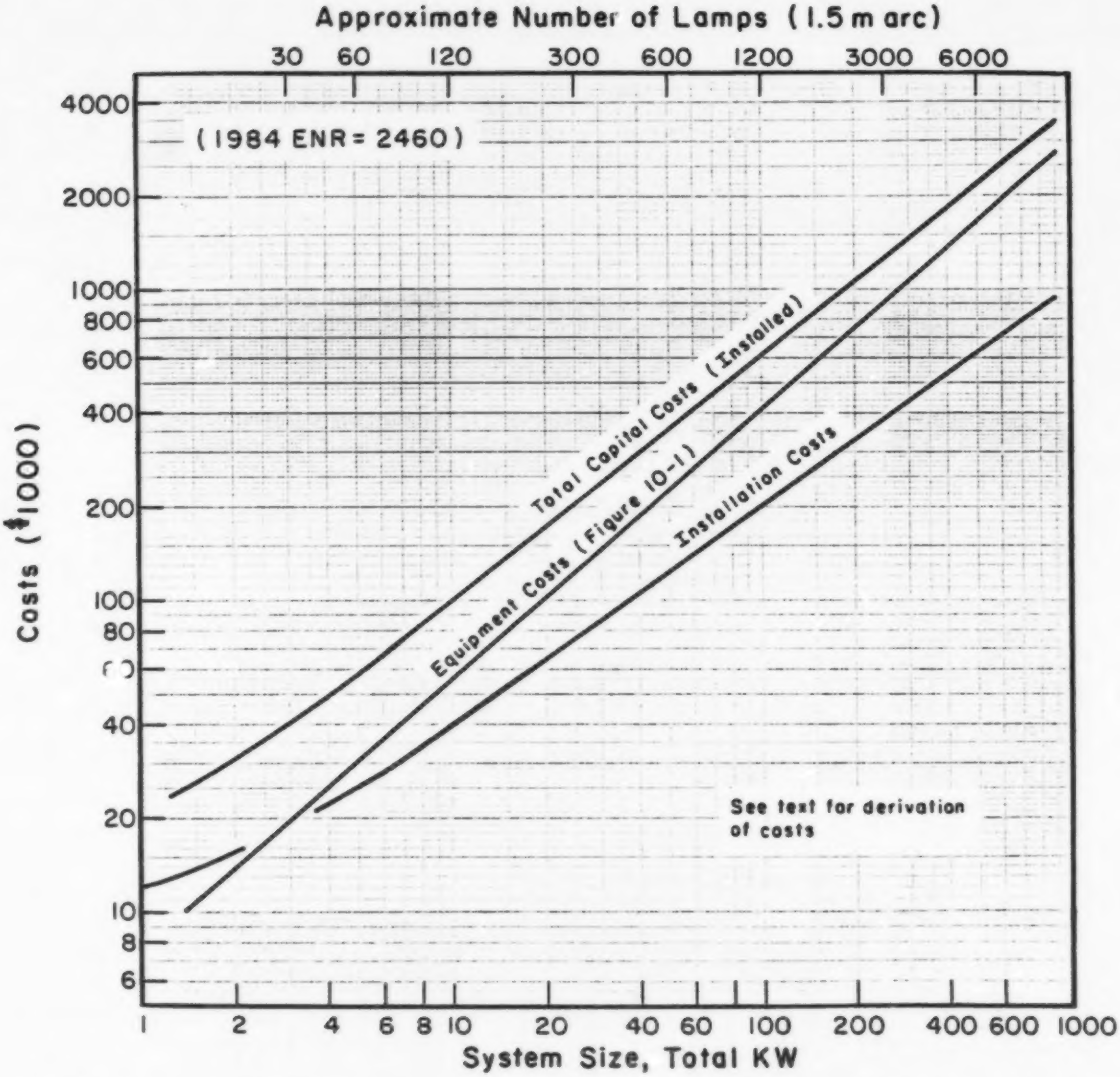


Figure 10-2. Capital costs for UV disinfection system as a function of system total power.

Space requirement = 25 square meters per module times 3 = 75 meter^2

Equipment Cost

From Figure 10-1, 50 kW system................	$220,000

Installation Cost

Structural, 75 m^2 times \$800/m^2...............	\$ 60,000
Installation, 20 percent of equipment.........	\$ 44,000
Engineering, 10 percent of structural and installation costs...................	\$ 10,400
Contingency, 25 percent of structural.........	\$ 15,000
Total Cost, 50 kW system......................	\$349,400

The precision of the estimates provided on Figure 10-2 is estimated to be -20 and +35 percent. It is clear from this analysis, that the major element of the capital costs for the UV process is the equipment itself. The total installed costs are approximately 1.5 to 2 times the total hardware costs.

O&M COSTS

UV is a capital intensive process, with the equipment requirements directly proportional to the design peak hydraulic and performance needs. The O&M needs, however, are reflected more by the average utilization of the system. In fact, a key operational consideration is to use only that portion of the system necessary to meet current performance demands. Over-utilization of the system, in an attempt to simplify operations, will have a significant impact on the costs to operate the process. The following discussions focus on the three major elements which comprise the costs associated with the O&M of a UV system.

Labor Requirements

Estimating labor requirements is a subjective task, relying on current experiences and being selective in defining the tasks which should be assigned to the UV process. In estimating the labor needs, the experience in the operation of the Port Richmond plant was assessed, as well as previous studies and the current experience at full-scale facilities. The estimates are summarized in graphical form on Figure 10-3. As shown, the labor is divided into three major categories: direct UV O&M tasks; general maintenance; and system overhaul. It is important to note that the labor estimates are based on the O&M requirements for the entire installed system.

Direct UV O&M--

The tasks which are considered in this category may be described as follows:

O&M--

- Daily systems checks for proper operation.
- Appropriate recording of data (lamps in operation, meter readings, power readings, flow rates, water quality readings, temperatures, etc.).
- Sampling and analysis for suspended solids, bacterial density, UV absorbance.
- Direct manual control of the systems, or the monitoring and control of automatic operational instrumentation.

Maintenance--

- Checking and maintaining system components (lubrication, etc.).
- Storage and maintenance of appropriate parts inventory.
- Routine system cleaning. The labor associated with this task will include monitoring of the quartz/teflon surfaces, switching systems during special cleaning cycles, and maintenance of the chemical feed systems.
- Replacement of worn or broken components in the system.

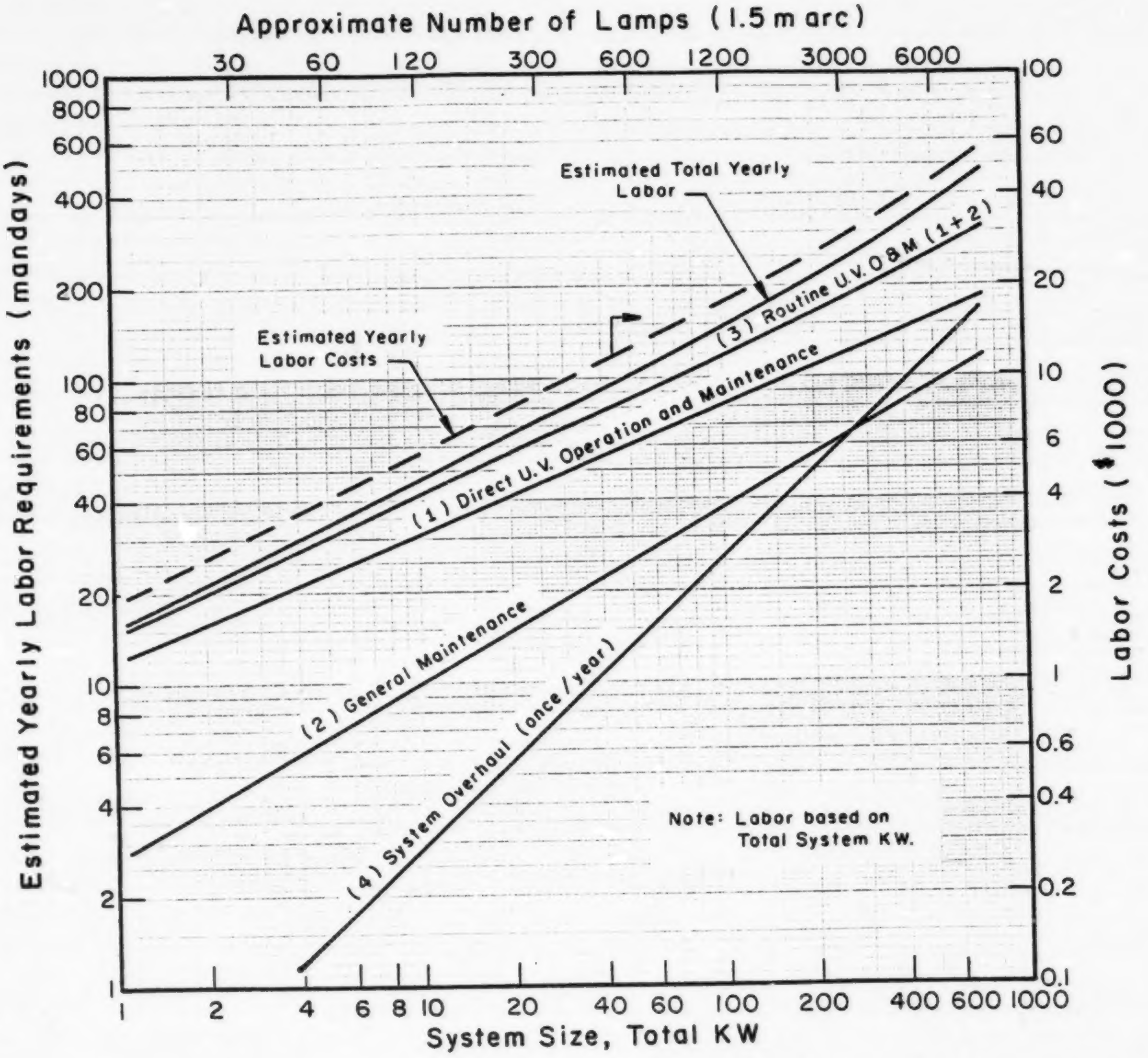


Figure 10-3. Estimate of labor requirements and costs for the O&M of UV systems.

The labor needs assigned to these direct O&M tasks are estimated to range from two to three hours per week for the small systems (less than 100 lamps) to 15 to 30 hours per week for the larger plants (greater than 1500 lamps).

General Maintenance--

As had been discussed, there are space, building, and ventiliation requirements associated with the installation of a UV process. The general maintenance of these physical facilities will be required. For purposes of this discussion the labor is assigned to the labor requirements for the disinfection process at a plant. It is estimated to be approximately one-half that required for the direct O&M tasks discussed above.

System Overhaul--

The reader is referred to the discussions in Section 7 which dealt with the cleaning and direct measurement of the lamps and the quartz/teflon which comprise the UV reactor. It is strongly recommended that the entire system be broken down on a yearly basis to accomplish the following tasks:

- Clean the outside surface of each lamp.
- Clean the inside surfaces of each quartz sleeve, and the outside surfaces of the teflon tubes.
- Measure each lamp for relative UV output; replace those which fall below a specified level.
- Measure a representative sampling of the quartz/teflon enclosures for transmissibility; replace those which are worn excessively.
- Check internal components for wear and replace if necessary.

As had been discussed earlier in the report, these tasks are suggested to serve as an efficient means to control the system's output and energy efficiency at acceptable levels. By having direct measurements of the unit's average output, the lamps can be utilized to their maximum life. Keeping the surfaces clean will allow for efficient use of the UV energy. As will be shown in the following subsection, the lamps and power comprise two of the three major cost elements for the O&M of a UV system.

Based on the experiences at Port Richmond, the labor required to accomplish the system overhaul each year is estimated to be approximately 16 hours per 100 lamps. Relative to the total labor requirements for the UV process, the system overhaul is small but can yield significant overall O&M cost savings.

Total Labor Estimates--

The total yearly estimated labor requirement is presented on Figure 10-3. Note that these are based on year-round disinfection. In cases where seasonal disinfection is allowed, the labor estimates for the direct O&M, and the general maintenance tasks would be reduced; the system overhaul is still recommended on a yearly basis.

Overall the labor needs for the UV process are relatively low, ranging from approximately 47 mandays for a small 10 kW (120 lamps) system to approximately 320 mandays for a 400 kW system (5000 lamps). A unit cost of $100 per manday is assigned to these labor estimates to determined the O&M labor costs. These estimates are also presented on Figure 10-3.

Materials Costs

The major material costs associated with the UV system are the lamps, the ballasts, and the quartz or teflon enclosures. To estimate the annual average requirement for materials, the following assumptions are made:

Lamps--

- Low pressure mercury arc, 1.5 meters arc.
- Replacement cycle is one year (8700 hours); this is conservative; there are cases where considerably longer life cycles have been shown.
- Unit cost of $50 per lamp.

Ballasts--

- A single ballast serves two lamps.
- The average life cycle is five years; this can be be considered conservative if the ballast is properly mated and the power panel is properly ventilated to prevent overheating.
- Unit cost of $65 per ballast.

Quartz/Teflon Enclosures--

- One enclosure per lamp.
- An average life cycle of five years.
- Unit cost of $50 per 1.5 meter long enclosure.

Miscellaneous--

- To account for miscellaneous parts replacements, a cost equivalent to five percent of the annual lamps, ballasts, and enclosures costs is assumed. Chemical costs for cleaning are also included in this category. If very frequent cleaning is necessary, the relative costs may rise.

The estimated material costs are presented on Figure 10-4. Note that these costs are presented as a function of the annual average system utilization (kW). Thus, although the system may be sized to meet the peak power demand, the need to replace the major expendable components of the system will depend on their actual use; this can be represented be the estimated annual average utilization of the system.

Power Costs

The third cost element, power, is estimated on the basis of the annual average system utilization and a unit cost of $0.08 per kW-hr. Obviously, this rate will vary from region to region in the country and should be adjusted to reflect actual site conditions. The power costs are presented on Figure 10-4.

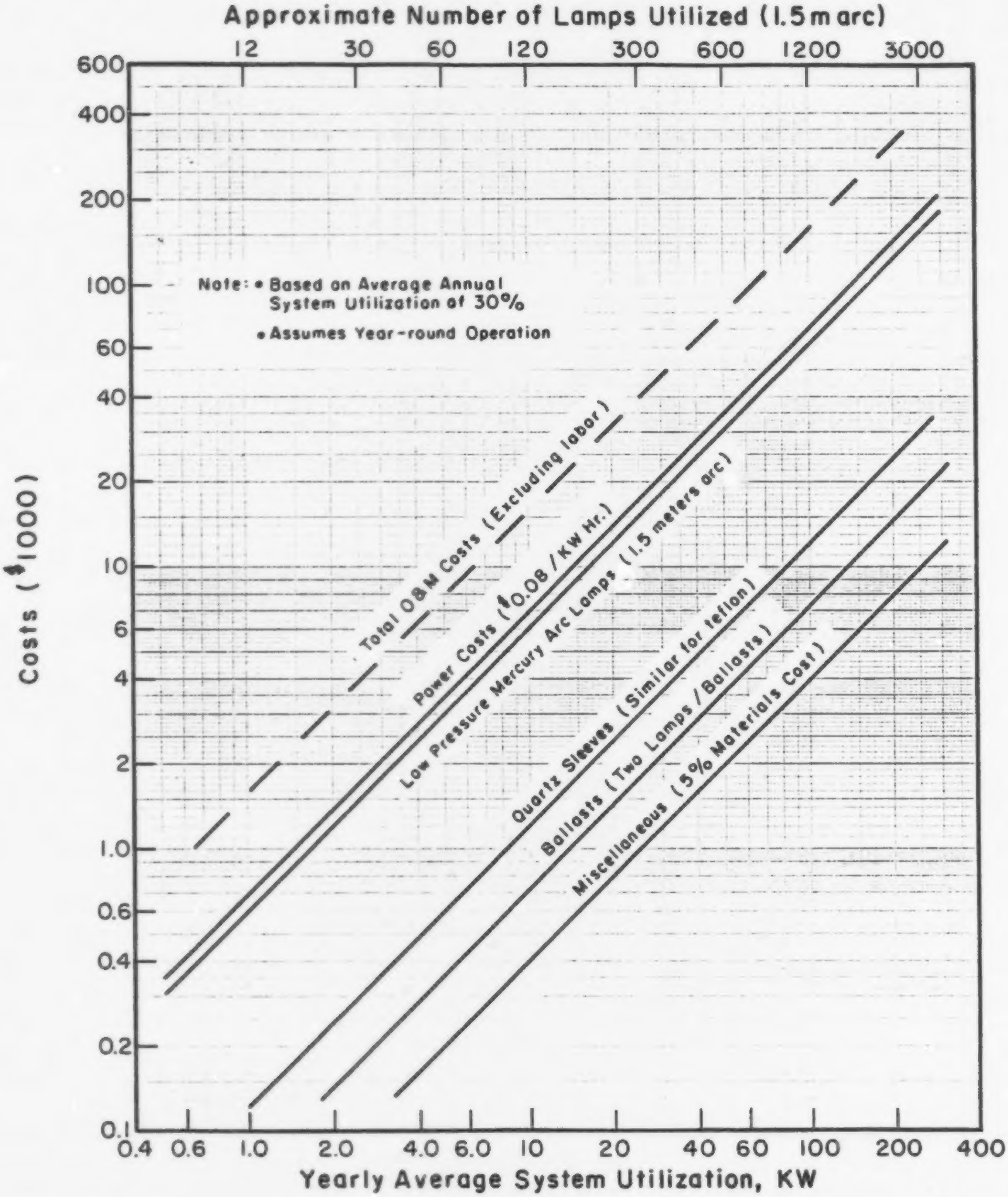


Figure 10-4. Estimates of materials and power costs for UV systems.

Annual O&M Costs

Figure 10-4 also presents the total O&M costs, summing the costs of the power and replacement materials. This does not include the labor costs. In order to estimate the total annual O&M for a system, Figure 10-5 was constructed. The annual average utilization was assumed to be 30 percent of the total system size, in order to relate the materials and power costs (Figure 10-4) to the total system. The labor estimated is that derived on Figure 10-3. The total annual O&M costs (assuming year-round operation and an average utilization of 30 percent) are then determined by adding the labor, materials, and power costs.

Of the material costs, the lamps comprise approximately 75 percent of the cost. Materials comprise approximately 20 percent of the total O&M for the smaller systems; this increases to approximately 40 percent for the large systems. Power (at the given unit rate) accounts for 10 percent of the total O&M for a small system, increasing to approximately 30 percent the cost in large systems. Labor accounts for the greater share of the costs at the lower system size levels (approximately 70 percent), steadily decreasing in share as size increases; the labor costs for large systems comprises approximately 30 percent the total O&M costs.

ANNUAL COSTS FOR UV DISINFECTION SYSTEMS

The total annual costs for UV disinfection are also presented on Figure 10-5. These include the total estimated O&M costs and the capital costs amortized over a period of 20 years at an interest rate of 7 percent. The annual costs range between approximately $10,000 per year for a small 4 kW system to $350,000 per year for a large 400 kW system. The annual O&M costs are estimated to constitute approximately 60 to 70 percent of the total annual costs.

COST ANALYSIS EXAMPLE FOR A SECONDARY WASTEWATER DISINFECTION APPLICATION

The cost estimates which are provided in the previous discussions are all based on the UV system size, expressed as the total kW draw of the

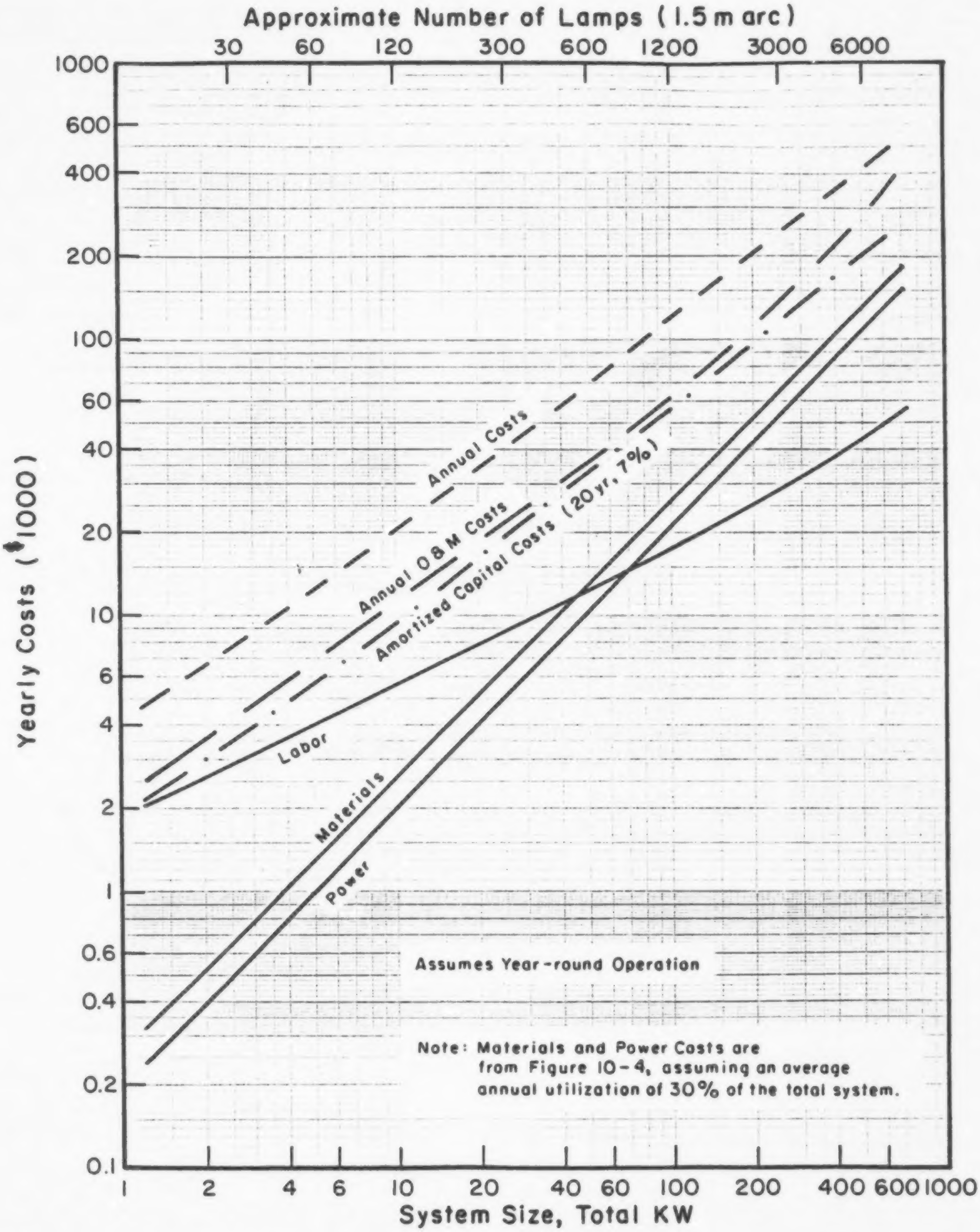


Figure 10-5. Estimated annual costs, assuming an annual average 30 percent utilization of the total system.

system. Thus, in order to determine a cost estimate for a given application, it is necessary to size the system requirements for a given wastewater application. This will be site specific, depending on the hydraulic loads, the wastewater characteristics, and the required performance.

An example is provided for a "typical" secondary effluent for wastewater treatment plants ranging in size from 2.63 m^3/min (1.0 mgd) to 263 m^3/min (100 mgd). It is assumed that the critical design condition for the UV design is the maximum 30-day average (GM) fecal coliform of 200 colonies per 100 ml. The effluent is characterized as follows:

Design peak flow to average flow ratio = 2.0
Average UV absorbance coefficient = 0.4 cm^{-1}
Ratio 30-day to average UV absorbance coefficient = 1.2
Average suspended solids = 20 mg/1
Maximum 30-day average suspended solids = 30 mg/1
Average effluent fecal coliform density = 200,000 colonies /100 ml
Maximum 30-day effluent coliform density = 300,000 colonies/100 ml

Consider the calculations for a quartz system to handle an annual average daily flow of 26.3 m^3/min (10 mgd). The system is sized on the basis of the calibrated model derived for the Port Richmond study and presented in Section 8. The unit is assumed to have a spacing of 5.0 cm; the average lamp output is 80 percent nominal, with an average transmissibility of the quartz maintained at 75 percent.

The size of the system will be set by the 30-day peak conditions. The required performance will be a log reduction of 5.3 (log of 200,000), assuming that the allowable effluent density of 200 colonies/100 ml will be associated with the suspended solids in the effluent. At a maximum 30-day average absorbance coefficient of 0.48 cm^{-1}, the average system intensity is estimated to be 5400 μWatts/cm^2 (from Figure 8-4, 9000 x 0.75 x 0.8 = 5400). Referring to Figure 8-23 (upper panel) the allowable loading to achieve a Log L/L_o of -5.3 is 1.5 lpm/UV watt nominal. This then yields the total lamp requirement, assuming 1.5 m arc lamps with a nominal UV output of 26.7 watts. The design flow is two times the average daily, or $52.6 m^3$/min, which is equivalent to 52600 lpm:

Nominal watts at 253.7 nm = 52600 lpm/(1.5 lpm/UV watt) = 35000 watts
Total number of lamps = 35000 watts/(26.7 watts/lamp) = 1310 lamps
Total system power = 1310 x 80 watts/lamp = 105 kW

Similarly, the annual average system utilization can be estimated, based on the average wastewater characteristics. The average intensity, at an absorbance coefficient of 0.40 cm-1 is 6600 μWatts/cm^2. The effluent fecal coliform density associated with the suspended solids is approximately 100 colonies per 100 ml; the performance requirement is therefore:

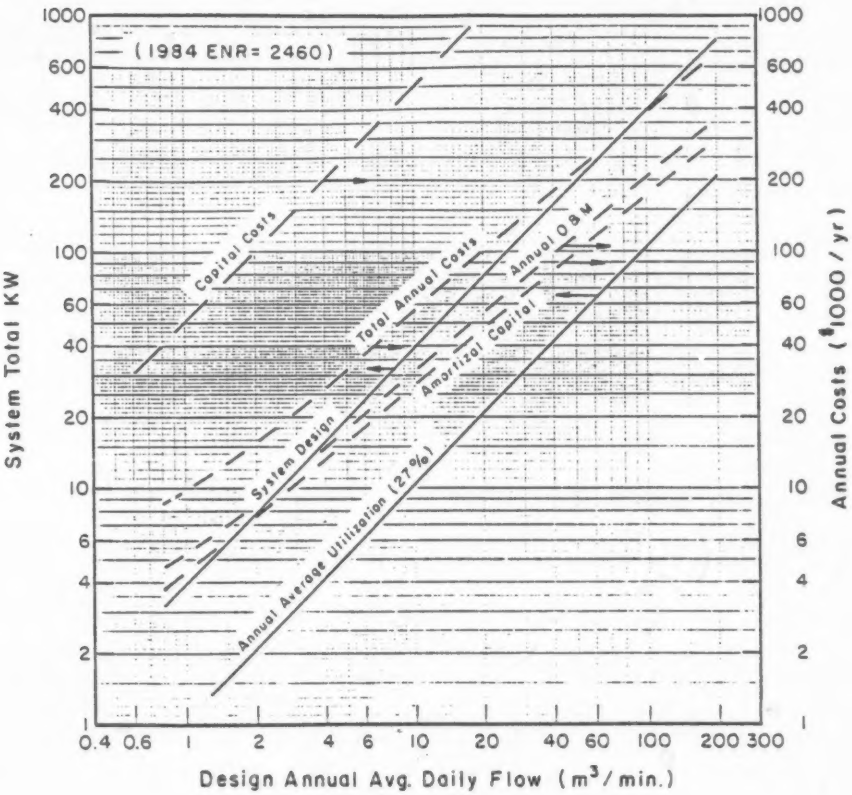
$$\text{Log } L/L_o = \text{Log } (200 - 100)/200000 = - 3.3$$

Referring again to Figure 8-23, the allowable loading is 2.8 lpm/UV watt. At the average flow of 26300 lpm,

Nominal watts = 26300 lpm/ (2.8 lpm/UV watt) = 9,400 watts
Total number of lamps = 9400 watts/(26.7 watts/lamp) = 352 lamps
Annual average utilization = 352 x 80 = 28.2 kW

Thus, the average annual utilization is approximately 27 percent of the total installed system. This also presumes that the system is at capacity upon startup. Presuming linearity of costs with plant size, Figure 10-6 presents the design sizing and the average system utilization for a range of design average flow rates. These estimates apply only to the characteristics and assumptions discussed above and reiterated on the figure.

The capital and annual costs are also presented on Figure 10-6 as a function of the design average flow capacity of the plant. These costs are derived from Figures 10-4 (power and material costs) and 10-5 (capital and labor costs). Considering again the plant with a design average flow of



Assumptions: Design based on requirement for maximum 30-day average (GM) fecal coliform of 200 colonies/100 ml.
System at Capacity; year-round disinfection.

Peak design flow = 2 x Average Daily Flow
Average α_s = 0.4 cm^{-1}
Maximum 30-day average α_s = 0.48 cm^{-1}
Average SS = 20 mg/l
Maximum 30-day average SS = 30 mg/l
Average L_o = 200,000 col/100 ml
Maximum 30 day average L_o = 300,000 col/100 ml
Quartz Spacing = 5.0 cm
Quartz Average Transmittance = 75 percent
Average UV output = 80 percent

Figure 10-6. Quartz system sizing and costs analysis for application to "typical" secondary effluent.

26.3 m^3/min (10 mgd), the annual costs (including amortized capital costs) are estimated to be $125,000. This yields a unit cost of $0.009 per cubic meter ($0.034 per 1000 gallons).

COMPARISON OF COSTS FOR ALTERNATIVE DISINFECTION SYSTEMS

A comparison of costs had been performed in 1979 as part of a similar evaluation of UV disinfection.(9) This study had assembled unit costs for a number of disinfection processes and compared them to the estimated unit cost for UV disinfection. These same unit costs are presented on Figure 10-7, updated to 1984 (USEPA Index = 460) and compared to the unit costs developed for UV disinfection as part of this project. It is important to reiterate the conditions noted by the first report. The costs were derived from a number of sources (repeated herein; see References 21 through 26). In certain cases, a wide range in cost estimates was found for a specific process. The values used on Figure 10-7 represent an approximate average of the various estimates. Additionally, the costs presented in various sources may differ in their assumptions for labor, power, etc. Caution is therefore, warranted in any direct cost comparisons.

The analysis presented on Figure 10-7 suggests that UV is considerably less expensive than ozonation and is competitive, if not less expensive, than the chlorination or chlorination/dechlorination processes. It was found that the costs estimated for UV in this study were less than the estimates from the 1979 report. The reasons for this are primarily the reduction in real costs for equipment and the more rational manner in which UV systems can now being designed.

DESIGN/COST EXAMPLE FOR THE DISINFECTION OF PRIMARY WASTEWATERS

An element of the Port Richmond project was directed to determining the feasibility of using UV for the disinfection of CSO wastewaters. Primary effluent was used to simulate these types of wastewaters for the experimental program. The results had been presented in Section 7; the data were also utilized in the calibration of the model, as presented in Section 8.

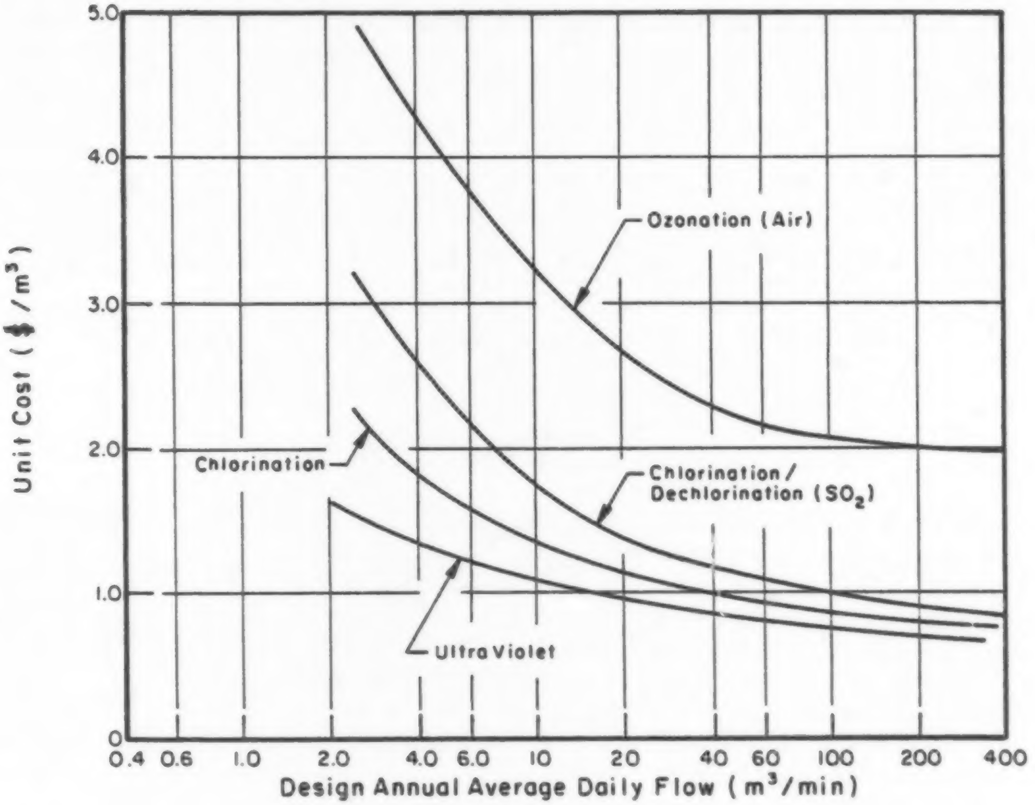


Figure 10-7. Comparison of unit costs for alternative disinfection processes.

It is not in the scope of this study to determine the design requirements for a CSO system. Such an analysis requires information on rainfall/runoff statistics for the area in question and the regulator operations for the collection systems. The UV system design will be greatly influenced by the peak flow requirements; these in-turn reflect the factors of rainfall intensity, duration, frequency of occurrence, etc.

An example can be provided which considers the UV disinfection of a primary effluent. This will provide some indication of the system requirements and costs relative to the "typical" secondary effluent. Consider, again, the calculations for a quartz system to treat an annual average primary effluent flow of 26.3 m^3/min (10 mgd). The unit will have a spacing of 5.0 cm. The lamp output and the quartz transmittance will be maintained at an average of 80 and 75 percent, respectively.

Based on the primary effluent analyses during the Port Richmond study, let the "typical" primary effluent have the following characteristics:

Design peak flow to average flow = 2.0
Average UV absorbance coefficient = 0.6 cm^{-1}
Ratio 30-day average to mean = 0.7 cm^{-1}
Average suspended solids = 80 mg/1
Maximum 30-day average = 100 mg/1
Average fecal coliform density = 1.3×10^7
Maximum 30-day fecal coliform density = $2. \times 10^7$

Let the system size be set by the anticipated maximum 30-day condition. The performance standards for primary effluent disinfection (or CSO disinfection) are generally set by water quality requirements. For purposes of this discussion, consider the system needs to yield an effluent fecal coliform density of 5000 colonies/100 ml. The density associated with the suspended solids may first be estimated:

$$L_{SS} = 0.25\ (100)^2 = 2500$$

$$L^\circ = L - L_{SS} = 2500$$

The performance requirement can then be determined:

$$\text{Log } \frac{L}{L_o} = \text{Log } [\frac{2,500}{20,000,000}] = -3.9$$

The average system intensity at the 30-day maximum absorbance coefficient of 0.7 cm^{-1} is estimated to be 6200 μWatts/cm^2. To account for expected operating conditions, this is further adjusted:

$$I_{avg} = 6200 \times 0.80 \times 0.75 = 3720 \ \mu\text{Watts/cm}^2$$

The allowable loading (Figure 8-23) to achieve a log L/L_o of -3.9 is 1.2 lpm/UV watt nominal. The total lamp requirement can then be determined at the peak flow of 52.6 m^3/min (2 x 25.3 m^3/min), which is 52,600 lpm:

$$\begin{aligned}\text{Nominal watts at 253.7 nm} &= \text{52,600 lpm/(1.25 lpm/UV watt)}\\ &= \text{42,080 watts}\end{aligned}$$

$$\begin{aligned}\text{Total number of lamps} &= \text{42,080 watts/(26.7 watts/lamps)}\\ &= \text{1,576 lamps}\end{aligned}$$

$$\text{Total system power} = 1,576 \times 80 \text{ watts/lamp} = 126 \text{ kW}$$

The annual average system utilization can also be estimated. The average intensity (at an absorbance coefficient of 0.6 cm^{-1}) is 4,500 μWatts/cm^2. The fecal coliform density associated with the suspended solids is approximately 1600 col/100 ml; the performance requirement is then:

$$\text{Log } \frac{L}{L_o} = \text{Log } [(5000 - 1600)/13,000,000] = -3.6$$

The allowable loading is approximately 1.7 lpm/W_n. At an average flow of 26,300 lpm, the annual average lamp utilization can be determined:

Nominal watts = 26,300/(1.7 lpm/W_n) = 13,900 watts
Total number of lamps = 13,900/26.7 $\approx$ 520
Annual average power utilization = 520 x 80 = 41.6 kW

This is approximately 33 percent of the total installed system. From Figure 10-5, the annual costs are estimated to be $135,000/year, or approximately $0.01/$m^3$.

It is important to note, from the above analysis, the sensitivity to the design requirement of Log L/L_o. The effluent density was set at some multiple above the density associated with the suspended solids. The system size will greatly expand if the objective was to leave a residual which was associated only with the suspended solids. As an example, at the peak condition:

$L_{SS} \sim 2500$ col/100 ml

If we were to set this as the maximum effluent density, the required Log L/L_o would be approximately -7.1. The system size to meet this goal would be a total of 4900 lamps, which is more than three times the size determined to meet a density of 5000 FC col/100 ml. Careful consideration should be given to the acceptable effluent density levels and the subsequent impact on the UV process design.

REFERENCES

1. Brungs, William L., "Effects of Residual Chlorine on Aquatic Life," Journal Water Pollution Control Federation, 45, 2180, October 1973.

2. Ward, R.W. and G.M. DeGraeve, "Residual Toxicity of Several Disinfectants in Domestic Wastewater," Journal Water Pollution Control Federation, 50, 46, January 1978.

3. Piecuch, Peter, J., "The Chlorination Controversey," Journal Water Pollution Control Federation, 46, 2637, December 1974.

4. Venosa, A.D., "Current State-of-the-Art of Wastewater Disinfection," Journal Water Pollution Control Federation, 55, 457, May 1983.

5. Roeber, J.A. and F.M. Hoot, "Ultraviolet Disinfection of Activated Sludge Effluent Discharging to Shellfish Waters," NTIS, PB 249, 460, EPA-600/2-75-060, December 1975.

6. Oliver, B.G. and E.G. Cosgrove, "The Disinfection of Sewage Treatment Plant Effluents Using Ultraviolet Light," Canadian Journal of Chemical Engineering, 53: 170-174, April 1975.

7. Oliver, B.G. and J.H. Carey, "A Scale-up Investigation of Ultraviolet Disinfection as an Alternative to Chlorination for Sewage Effluents," Canadian Journal of Chemical Engineering, Vol 53, pg 711-712, December 1975.

8. Petrasek, Albert C., Jr., Wolf, Harold W., Esmond, Stephen E. and D. Craig Andrews, *Ultraviolet Disinfection of Municipal Wastewater Effluents*, EPA-600/2-80-102, USEPA Municipal Environmental Research Laboratory, Cincinnati, Ohio, August 1980.

9. Scheible, O.K., and Carlene D. Bassell, *Ultraviolet Disinfection of a Secondary Wastewater Treatment Plant Effluent*, USEPA Municipal Environmental Research Laboratory, EPA-600/2-81-152; NTIS, PB-81-242-125, September 1981.

10. Johnson, J. Donald and Robert G. Qualls, *Ultraviolet Disinfection of Secondary Effluent: Measurement of Dose and Effects of Filtration*, Report of USEPA Project R804770010, USEPA Municipal Environmental Research Laboratory, Cincinnati, Ohio 1981.

11. *Standard Methods for the Examination of Water and Wastewater*, 14th Edition, AWWA, WPCF, APHA, Washington, D.C., 1976.

12. *Microbiological Methods for Monitoring the Environment Water and Wastes*, Robert Bordner and John Winter, Editors, USEPA-600/8-78-017, 1978.

13. Bissonnette, G.C., Jazeski, J.J., McFeters, G.A., and D.G. Stuart, "Evaluation of Recovery Methods to Detect Coliforms in Water," *Applied Microbiology*, 33:590-595, 1977.

14. Qualls, R.G., and J.D. Johnson, "Bioassay and Dose Measurement in UV Disinfection," *Applied Environmental Microbiology*, 45:872-877, 1983.

15. Qualls, R.G., Flynn, M.P., and J.D. Johnson, "The Role of Suspended Particles in Ultraviolet Disinfection," *Journal Water Pollution Control Federation*, (In Press), 1984.

16. R.V. Thomann, *Systems Analysis and Water Quality Management*, McGraw Hill Book Company, New York, 1972.

17. Jacobs, S.M., and J.S. Dranoff, "Light Intensity Profiles in the Perfectly Mixed Photoreactor," Journal American Institute of Chemical Engineers, Volume 16, No. 3, May 1970.

18. Daugherty, Robert L. and Joseph B. Franzini, Fluid Mechanics with Engineering Applications, McGraw-Hill Book Company, New York, 6th Edition, 1965.

19. Kramers, H. and K.R. Westererp, Chemical Reactor Design and Operation, Netherlands University Press, Amsterdam, 1963.

20. In Press; Report on Eden, Wisconsin.

21. Opatken, E.J., "Economic Evaluation of Ozone Contactors," Proceedings of the National Symposium, Progress in Wastewater Disinfection Technology, Cincinnati, Ohio, September 18 to 20, 1978.

22. Patterson, W.L. and F.F. Banker, Estimating Costs and Manpower Requirements for Conventional Wastewater Treatment Facilities, EPA Office of Research and Monitoring, Contract #14-12-462. October 1971.

23. VanNote, R.H. et. al., A Guide to the Selection of Cost-Effective Wastewater Treatment Systems, USEPA Office of Water Programs Operations, Contract 68-01-0973, EPA-43/9-75-002, July 1975.

24. Water Pollution Abatement Technology, Metcalf and Eddy, Inc., for the National Commission on Water Quality, Washington, D.C., NCWQ75/43, March 1976.

25. Culp, Wesner, Culp, "Process Design, Performance and Economic Analysis Handbook, Biological Wastewater Treatment Processes," Wastewater Treatment and Reuse Seminar, South Lake Tahoe, California, October 26 to 27, 1977.

26. Mills, J.F., "The Chemistry and Disinfection Properties of Bromine Chloride," presented before the Division of Environmental Chemistry, American Chemical Society, New Orleans, March 1977.

APPENDIX A

DAILY OPERATIONAL LOG OF THE PORT RICHMOND PILOT FACILITY

The following is a digest of the operational log for the pilot facility, starting December 1, 1981 (day 001). The day number (000) is given first, followed by the data. Recall that Unit 1 is the widely spaced quartz system; Unit 2 is the closely spaced system; and Unit 3 is the teflon system.

001 12/1/81 Unit 1 Down
Unit 2 Down

Both units were under repair by PWS to replace burned ballasts. Ballasts have been overheating - suspected a short to ground: 5 replaced on Unit 2; 1 replaced on Unit 1. Unit 2 has 8 bulbs out in center bank.

002 12/2/81 Unit 1 Sampling (4X)
Unit 2 Sampling (4X)

Each unit sampled 4 times; 90%V setting on Variac will be standard.

003 12/3/81 Unit 1 Sampling (4X)
Unit 2 Sampling (4X)

Intensity monitors set to 100% total with all banks on.

004 12/4/81 Unit 1 Standby
Unit 2 Standby

Flow was shutdown for approximately 1 hour to repair leaks in 18 in. effluent line.

005 12/5/81 Unit 1 Standby
Unit 2 Standby

006 12/6/81 Unit 1 Standby
Unit 2 Standby

007 12/7/81 Unit 1 Sampling (2X)
Unit 2 Sampling (1X)

Units were down part of the day. All bulbs which had been out were replaced by PWS. Unit intensity monitor was repaired.

008 12/8/81 Unit 1 Down
Unit 2 Down

Units were shutdown due to severe foaming conditions at the plant. Unable to startup-foaming would reoccur almost immediately. Cleaned outside area with firehose.

009 12/9/81 Unit 1 Down
Unit 2 Down

No success in startup - foaming would quickly become excessive. Opened bypass valve to flush channel. Turned on CSO pump - highly septic flow. Cancelled any sampling.

010 12/10/81 Unit 1 Down
Unit 2 Down

No success in startup of spray water pump - excessive foaming in units. Ran hydraulic studies on Units 1 and 2, using tap water (fire hydrant).

011 12/11/81 Unit 1 Down
Unit 2 Down

Foaming still a problem - kept pumps off. Excessive carryover of water - freezing.

012 12/12/81 Unit 1 Down
Unit 2 Down

013 12/13/81 Unit 1 Down
Unit 2 Down

014 12/14/81 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

Unit 1 leaking badly at bulkhead. Unit 2 leaking from east side when wiper moves. Intensity monitors set to 100% with all banks on; read each bank individually.

015 12/15/81 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

Unit 1 leaking badly near lamps. One of 3 fans out in Power Panel for Unit 2.

016 12/16/81 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)

Unit 1 still leaking. Second sampling (at high flow) had considerable foaming in head tanks.

017 12/17/81 Unit 1 Sampling (2X)
Unit 2 Sampling (3X)

Foaming a problem. Difficult to run units for sampling at higher flows. Unit 1 still leaking.

018 12/18/81 Unit 1 Standby
Unit 2 Standby

019 12/19/81 Unit 1 Standby
Unit 2 Standby

020 12/20/81 Unit 1 Standby
Unit 2 Standby

021 12/21/81 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

Unit 1 leaking badly (worse when wiper is running); shutdown after last sampling - leaking water was causing severe icing on driveway.

022 12/22/81 Unit 1 Standby
Unit 2 Standby

Leak repaired by PWS on Unit 1. Hydraulics study runs made using tap off fire hydrant.

023 12/23/81 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

024 12/24/81 Unit 1 Standby
Unit 2 Standby

025 12/25/82 Unit 1 Standby
Unit 2 Standby

026 12/26/81 Unit 1 Standby
Unit 2 Standby

027 12/27/81 Unit 1 Standby
Unit 2 Standby

028 12/28/81 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

029 12/29/81 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

Air compressor leaking water at head. Air in valves at Power Panel 1. Wiper cable in Unit 2 snapped between sampling 1 and 2.

030 12/30/81 Unit 1 Standby
Unit 2 Down

Wiper broken on Unit 2

031 12/31/81 Unit 1 Standby
Unit 2 Down

032 1/1/82 Unit 1 Standby
Unit 2 Down

033 1/2/82 Unit 1 Standby
Unit 2 Down

034 1/3/82 Unit 1 Standby
Unit 2 Down

035 1/4/82 Unit 1 Sampling (4X)
Unit 2 Down

PWS replacing cable on Unit 2. Unit 1 wiper rate improperly set to zero - reset.

036 1/5/82 Unit 1 Down
Unit 2 Down

037 1/6/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

038 1/7/82 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)

Difficult to sample at higher flows due to foaming. Wiper on unit 2 not operating - timer set incorrectly and air line disconnected. PWS indicated that cable housing on Unit 2 may have been cracked during replacement work. This may cause small leak but should not be a problem.

039 1/8/82 Unit 1 Standby
Unit 2 Standby

040 1/9/82 Unit 1 Standby
Unit 2 Standby

041 1/10/82 Unit 1 Standby
Unit 2 Standby

042 1/11/82 Unit 1 Sampling (1X)
Unit 2 Sampling (1X)

Each unit sampled at maximum flow. Some problems (overflow) with flume on Unit 1.

043 1/12/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

044 1/13/82 Unit 1 Standby
Unit 2 Standby

Day was spent in preparation for hydraulic evaluations.

045 1/14/82 Unit 1 Standby
Unit 2 Standby

Hydraulic studies done.

046 1/15/82 Unit 1 Standby
Unit 2 Standby

047 1/16/82 Unit 1 Standby
Unit 2 Standby

048 1/17/82 Unit 1 Standby
Unit 2 Standby

049 1/18/82 Unit 1 Standby
Unit 2 Standby

Hydraulic studies done.

050 1/19/82 Unit 1 Standby
Unit 2 Standby

Hydraulic studies done.

051 1/20/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

052 1/21/82 Unit 1 Down
Unit 2 Standby

Quartz leaking on Unit 1.

053 1/22/82 Unit 1 Down
Unit 2 Standby

054 1/23/82 Unit 1 Down
Unit 2 Standby

055 1/24/82 Unit 1 Down
Unit 2 Standby

056 1/25/82 Unit 1 Down
Unit 2 Standby

Pump had been shutdown when first arrived; could not determine why. PWS and HQI personnel began dissassembly of Unit 1 to replace broken quartz (No. 10); quartz was replaced and Unit was flow tested. No leaks.

057 1/26/82 Unit 1 Down
Unit 2 Standby

Unit 1 was reassembled and put back into service. Air leak in Unit 2 cylinder; tightening fittings improved it somewhat. Compressor becoming very noisy, oil level okay.

058 1/27/82 Unit 1 Down
Unit 2 Sampling (3X)

Unit 1 was leaking. Found that the quartz tube (No. 10) was again broken; shut down the unit. Unit 2 has air leaks at the cylinder and in the control box. Unit 2 intensity monitor not working.

059 1/28/82 Unit 1 Down
Unit 2 Sampling (3X)

060 1/29/82 Unit 1 Down
Unit 2 Standby

061 1/30/82 Unit 1 Down
Unit 2 Standby

062 1/31/82 Unit 1 Down
Unit 2 Standby

063 2/1/82 Unit 1 Down
Unit 2 Down

Attempted to replace quartz No. 10 on Unit 1. Found that wiper gland had fallen off - could not reset the quartz. Ceramic end caps broke off 2 bulbs when they were being disconnected. Unit 2 was shutdown because of Unit 1 servicing.

064 2/2/82 Unit 1 Down
Unit 2 Down

Both units down for repair work on Unit 1.

065 2/3/82 Unit 1 Down
Unit 2 Down

Unit 1 - replaced quartz 10. Found that quartz No. 20 was also leaking. PWS was brought in to replace No. 20; also No.

10 and 20 wiper glands. Unit 1 quartz tubes were cleaned with a soap solution provided by PWS (while system was drained). Both units were operating by the end of the day. Noted that bulbs and insides of quartz sleeves were dirty.

066 2/4/82 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)

067 2/5/82 Unit 1 Standby
Unit 2 Standby

068 2/6/82 Unit 1 Standby
Unit 2 Standby

069 2/7/82 Unit 1 Standby
Unit 2 Standby

070 2/8/82 Unit 1 Standby
Unit 2 Standby

Began reading with IL570 Radiometer; also temperature probe reading at the lamps.

071 2/9/82 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)

Unit 2 leaking through wiper cable

072 2/10/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

073 2/11/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

074 2/12/82 Unit 1 Standby
Unit 2 Standby

075 2/13/82 Unit 1 Standby
Unit 2 Standby

076 2/14/82 Unit 1 Standby
Unit 2 Standby

077 2/15/82 Unit 1 Standby
Unit 2 Standby

Compressor broken - pully had shattered. Spray water pump had shut down again - restarted.

078 2/16/82 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)

Air compressor was repaired. Water leaking from Unit 2 control box at the wiper solenoid valve. With compressor off line the water leaked back through the lines into the panel.

079 2/17/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

Very poor effluent; foaming at higher flows.

080 2/18/82 Unit 1 Down
Unit 2 Down

Severe foaming at plant. PWS brought in for maintenance of systems. Unit 2 completed today - all bulbs were removed and cleaned. The quartz (insides) were all cleaned.

081 2/19/82 Unit 1 Down
Unit 2 Down

Unit 1 cleaning completed today. Due to severe foaming at plant, units will remain shutdown for the weekend

082 2/20/82 Unit 1 Down
Unit 2 Down
(foaming)

083 2/21/82 Unit 1 Down
Unit 2 Down
(foaming)

084 2/22/82 Unit 1 Down
Unit 2 Down
(foaming)

085 2/23/82 Unit 1 Standby
Unit 2 Standby

Both units were acid/detergent cleaned. IL-570 measurements taken.

086 2/24/82 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)

Severe foaming again. Unit flow turned on only for very short time to accomplish sampling. System shutdown overnight. Air leak in Unit 2 cylinder.

087 2/25/82 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)

Severe foaming again. System kept shutdown except for short time to collect samples.

088 2/26/82 Unit 1 Down
Unit 2 Down

Severe foaming; shutdown for weekend.

089 2/27/82 Unit 1 Down
Unit 2 Down
(foaming)

090 2/28/82 Unit 1 Down
Unit 2 Down
(foaming)

091 3/1/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

No foaming. Unit 2 wiper down after second sampling. Many indicator lights on Unit 1 are off but bulbs are on.

092 3/2/82 Unit 1 Sampling (3X)
Unit 2 Down

Unit 2 wiper inoperative. PWS has been notified.

093 3/3/82 Unit 1 Sampling (3X)
Unit 2 Down

Unit 2 down due to wiper. Foaming a problem at higher flows. Shut down Unit 1 overnight as a precaution.

094 3/4/82 Unit 1 Sampling (3X)
Unit 2 Down

Unit 2 wiper still inoperative.

095 3/5/82 Unit 1 Standby
Unit 2 Down

PWS began repair of Unit 2. Cable needs to be replaced. Expect to complete repairs on Monday (day 098).

096 3/6/82 Unit 1 Standby
Unit 2 Down

097 3/7/82 Unit 1 Standby
Unit 2 Down

098 3/8/82 Unit 1 Sampling (3X)
Unit 2 Down

PWS repairing Unit 2 wiper cable. Unable to finish - did not have quartz tube replacement. Unit to be finished tomorrow.

099 3/9/82 Unit 1 Sampling (3X)
Unit 2 Down

Unit 2 still down for repairs. PWS on-site to replace broken quartz.

100 3/10/82 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)

Spray water pump was found shut-down in AM - restarted. Cleaned Unit 2 with acid/detergent. Ran several readings of voltage and current across Variac at settings 100% to 60%. Power meter appears to be reading approximately 1/2 draw. Variac adjusted from 90% to 100%. Noticeable increase in ozone.

101 3/11/82 Unit 1 Standby
Unit 2 Standby

Time spent preparing foundation for UTI unit.

102 3/12/82 Unit 1 Standby
Unit 2 Standby

103 3/13/82 Unit 1 Standby
Unit 2 Standby

104 3/14/82 Unit 1 Standby
Unit 2 Standby

105 3/15/82 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)

Units were down for approximately 2 hours to allow electricians to rewire power meter. One wire was originally bypassed, giving exactly 50% of the actual reading.

106 3/16/82 Unit 1 Sampling (1X)
Unit 2 Sampling (3X)

Unit 1 sampled only once. Subsequently noticed that the wiper was down. PWS (on-site) suggested addition of O-rings where the cable mounts to the piston.

107 3/17/82 Unit 1 Down
Unit 2 Sampling (2X)

Eighteen bulbs out on Unit 2 - primarily due to loose connections. Unit 2 also leaking. Unit 1 down - PWS expected tomorrow.

108 3/18/82 Unit 1 Down
Unit 2 Standby

109 3/19/82 Unit 1 Down-Standby
Unit 2 Standby

Unit 1 O-rings installed in wiper cylinder. Air still leaking excessively. Unit 1 cleaned after repair and put back in service.

110 3/20/82 Unit 1 Standby
Unit 2 Standby

111 3/21/82 Unit 1 Standby
Unit 2 Standby

112 3/22/82 Unit 1 Down
Unit 2 Down

Compressor blown. Units shutdown; flow kept on.

113 3/23/82 Unit 1 Down
Unit 2 Down

Units were turned on - compressor is out however - no wiper.

114 3/24/82 Unit 1 Down (standby)
Unit 2 Down (standby)

Units on - but no wipers. Ran batch studies in lab.

115 3/25/82 Unit 1 Down (standby)
Unit 2 Down (standby)

Units on - no wipers. Ran batch studies in lab. Checked temperature of lamps.

116 3/26/82 Unit 1 Down (standby)
Unit 2 Down (standby)

Compressor still down (waiting for new head). Left bulbs and flow on for weekend.

117 3/27/82 Unit 1 Down (standby)
Unit 2 Down (standby)

118 3/28/82 Unit 1 Down (standby)
Unit 2 Down (standby)
(compressor)

119 3/29/82 Unit 1 Down (standby)
Unit 2 Down (standby)
(compressor)

120	3/30/82	Unit 1 Down (standby) Unit 2 Down (standby) (compressor)
121	3/31/82	Unit 1 Down (standby) Unit 2 Down (standby) (compressor)
122	4/1/82	Unit 1 Down (standby) Unit 2 Down (standby) (compressor) Ran batch experiments in laboratory
123	4/2/82	Unit 1 Down (standby) Unit 2 Down (standby) (compressor) Ran batch experiments in laboratory
124	4/3/82	Unit 1 Down (standby) Unit 2 Down (standby) (compressor)
125	4/4/82	Unit 1 Down (standby) Unit 2 Down (standby) (compressor)
126	4/5/82	Unit 1 Down (standby) Unit 2 Down (standby) (compressor) Ran batch experiments in laboratory.
127	4/6/82	Unit 1 Down (standby) Unit 2 Down (standby) (compressor) Blizzard of '82! (lost results of batch experiment run on 4-5-82)
128	4/7/82	Unit 1 Down (standby) Unit 2 Down (standby (compressor)
129	4/8/82	Unit 1 Down (standby) Unit 2 Down (standby) (compressor)
130	4/9/82	Unit 1 Down (standby) Unit 2 Down (standby)

131 4/10/82 Unit 1 Down (standby)
Unit 2 Down (standby)
(compressor)

132 4/11/82 Unit 1 Down (standby)
Unit 2 Down (standby)
(compressor)

133 4/12/82 Unit 1 Down
Unit 2 Down

PWS on-site to replace compressor head. When they attempted to startup again - discovered extensive damage to both power panels.
40 Ballasts burned in Unit 1
28 Ballasts burned in Unit 2
Systems were shut down again! Cause of damage is unknown.

134 4/13/82 Unit 1 Down
Unit 2 Down

PWS on-site to repair power panels. Set up for Lithium tracer studies. Repaired flow meter No. 1.

135 4/14/82 Unit 1 Down
Unit 2 Down

PWS on-site. Ran lithium flow studies to check calibrations.

136 4/15/82 Unit 1 Down
Unit 2 Down

PWS on-site repairing units: replacing ballasts; rewiring indicator panels; replacing defective cable on Unit 2 wiper; repairing air leaks at cylinder on Unit 1.

137 4/16/82 Unit 1 Down
Unit 2 Down

PWS on-site. Unit 1 operable electrically - still has severe air leak in wiper cylinder.

138 4/17/82 Unit 1 Down
Unit 2 Down

139 4/18/82 Unit 1 Down
Unit 2 Down

140 4/19/82 Unit 1 Down
Unit 2 Down

PWS not on-site today. Cleaned Unit 1 and ran intensity profiles with tap water.

141 4/20/82 Unit 1 Down
Unit 2 Down

PWS not on-site today. Using tap water in Unit 1 ran intensity studies. Unit 2 is still apart.

142 4/21/82 Unit 1 Down
Unit 2 Down

PWS on-site to work on units (expect to finish this week). Unit 1 has severe air leak.

143 4/22/82 Unit 1 Down
Unit 2 Down

PWS on-site for repair work.

144 4/23/82 Unit 1 Down
Unit 2 Down

PWS on-site for repair work. Both units operable by end of day.

145 4/24/82 Unit 1 Standby
Unit 2 Standby

146 4/25/82 Unit 1 Standby
Unit 2 Standby

147 4/26/82 Unit 1 Standby
Unit 2 Standby

148 4/27/82 Unit 1 Standby
Unit 2 Down

Ran intensity measurements. Unit 2 leaking around the bulbs and cylinder - had to be shutdown. PWS notified.

149 4/28/82 Unit 1 Sampling (2X)
Unit 2 Down

Unit 2 wiper leaking and spraying ends of bulbs.

150 4/29/82 Unit 1 Sampling (1X)
Unit 2 Down

Severe foaming. Shutdown Unit 1 after one sampling. Unit 2 shutdown. PWS not on-site.

151 4/30/82 Unit 1 Standby
Unit 2 Down

PWS on-site. Unit 2 operable by end of day.

152 5/1/82 Unit 1 Standby
Unit 2 Standby

153 5/2/82 Unit 1 Standby
Unit 2 Standby

154 5/3/82 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)

Cleaned Unit 2 before sampling.

155 5/4/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

Unit 2 leaking again.

156 5/5/82 Unit 1 Sampling (2X)
Unit 2 Sampling (2X) - Down

Unit 2 Down. Wiper broken - dismantled that afternoon; found the cable to be damaged.

157 5/6/82 Unit 1 Sampling (3X)
Unit 2 Down

Wiper down on Unit 2. PWS studying problems.

158 5/7/82 Unit 1 Standby
Unit 2 Down

159 5/8/82 Unit 1 Standby
Unit 2 Down

160 5/8/82 Unit 1 Standby
Unit 2 Down

161 5/10/82 Unit 1 Sampling (2X)
Unit 2 Down

PWS indicated wiper on Unit 2 broken due to defective cylinder blocks. New blocks were being shipped by manufacturer - expected 5/12/82.

162 5/11/82 Unit 1 Sampling (1X)
Unit 2 Down

PWS onsite for wiper. Severe foaming again. Shut down after first sampling.

163 5/12/82 Unit 1 Down
Unit 2 Down

Unit 2 being repaired by PWS; (indicate we should reduce the wiper frequency to once every few hours). Severe foaming prevented any sampling. Kept system shutdown. Ran several lab experiments.

164 5/13/82 Unit 1 Down
Unit 2 Down

Unit 2 is operable. Both units down due to severe foaming. Will leave both units down until Monday (5/17/82).

165 5/14/82 Unit 1 Down
Unit 2 Down
(foaming)

166 5/15/82 Unit 1 Down
Unit 2 Down
(foaming)

167 5/16/82 Unit 1 Down
Unit 2 Down
(foaming)

168 5/17/82 Unit 1 Sampling (1X)
Unit 2 Sampling (1X)

Spray water pump keeps kicking out - plant notified. Acid/detergent cleaned both units. Wiper on Unit 2 was not working - needed to tighten air lines. Serviced the compressor.

169 5/18/82 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)

Plant electricians checked spray water pump - may be overheating in warmer weather. Bearings may also be going. Unit 2 leaking - can't find source.

170 5/19/82 Unit 1 Down
Unit 2 Down

Several ballasts in Unit 2 power panel overheated - shutdown power.

171 5/20/82 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)

Power panels on both units very hot. UTI teflon unit finally arrived (approximately 8 months after is contracted delivery date). Unloaded from truck.

172 5/21/82 Unit 1 Standby
Unit 2 Down

Wiper cable jammed and snapped off the pulley on Unit 2. Several of quartz tubes were broken. PWS notified. They will be on-site over the weekend.

173 5/22/82 Unit 1 Standby
Unit 2 Down

174 5/23/82 Unit 1 Standby
Unit 2 Down

175 5/24/82 Unit 1 Standby
Unit 2 Down-Standby

Were to start replicate series for direct comparison of units, however, Unit 2 was inoperable until the end of the day.

176 5/25/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

Both units acid/detergent cleaned. Some difficulty with high flow measurements - tendency to overflow flumes.

177 5/26/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

Both units acid/detergent cleaned.

178 5/27/82 Unit 1 Standby
Unit 2 Standby

179 5/28/82 Unit 1 Standby
Unit 2 Standby

180 5/29/82 Unit 1 Standby
Unit 2 Standby

181 5/30/82 Unit 1 Standby
Unit 2 Standby

182 5/31/82 Unit 1 Standby
Unit 2 Standby

183 6/1/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

Both units acid/detergent cleaned. PWS drilled vents in top of power panels. Nine ballasts burned out in Unit 1; PWS notified.

184 6/2/82 Unit 1 Down
Unit 2 Down

Severe foaming. Unable to sample.

185 6/3/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

Both units acid/detergent cleaned.

186 6/4/82 Unit 1 Standby
Unit 2 Standby

Six ballasts out in each unit. PWS notified that they must be replaced immediately. PWS indicated they would be on-site 6/8/82.

187 6/5/82 Unit 1 Standby
Unit 2 Standby

188 6/6/82 Unit 1 Standby
Unit 2 Standby

189 6/7/82 Unit 1 Standby
Unit 2 Standby

No sampling due to problems with ballasts. Started installation of Teflon unit.

190 6/8/82 Unit 1 Down
Unit 2 Down

Units down to replace ballasts. Piping for Teflon unit being installed.

191 6/9/82 Unit 1 Down
Unit 2 Down

Units down to replace ballasts. When started - Unit 2 panel (resister bar) began to smoke; shutdown and notified PWS. Piping for teflon unit completed today.

192 6/10/82 Unit 1 Standby
Unit 2 Down

PWS was on-site to inspect Unit 2 to determine causes for shorting and problems with ballast. PWS believes the lamps are getting wet; don't believe this is case - unless there are leaks. Piping supports built for teflon unit.

193 6/11/82 Unit 1 Standby
Unit 2 Down - Standby

PWS repaired Unit 2. Installation work for teflon unit continued.

194 6/12/82 Unit 1 Standby
Unit 2 Standby

195 6/13/82 Unit 1 Standby
Unit 2 Standby

196 6/14/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

Both units acid/detergent cleaned. Air compressor serviced. Noticed Unit 2 wiper inoperative at end of day.

197 6/15/82 Unit 1 Sampling (3X)
Unit 2 Down

Wiper on Unit 2 inoperative. PWS notified.

198 6/16/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

Both units acid/detergent cleaned. PWS replaced solenoid valve in wiper system. Bulbs 71-74 not repaired (bad ballast). Spray water pumped kicked out in morning and again in afternoon. Quartz leaking in Unit 1. When tightened, it broke, and flooded the floor. Replaced by PWS.

199 6/17/82 Unit 1 Standby
Unit 2 Standby

Lithium tracer study done. Spray water pump shut off twice.

200 6/18/82 Unit 1 Standby
Unit 2 Standby

201 6/19/82 Unit 1 Standby
Unit 2 Standby

202 6/20/82 Unit 1 Standby
Unit 2 Standby

203 6/21/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

Both units acid/detergent cleaned. Pump shut off twice.

204 6/22/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

Both units acid/detergent cleaned. No problem with spray water pump.

205 6/23/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

Both units acid/detergent cleaned.

206 6/24/82 Unit 1 Standby
Unit 2 Standby

207 6/25/82 Unit 1 Standby
Unit 2 Standby

208 6/26/82 Unit 1 Standby
Unit 2 Standby

209 6/27/82 Unit 1 Standby
Unit 2 Standby

210 6/28/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

Both units acid/detergent cleaned.

211 6/29/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

Both units acid/detergent cleaned.

212 6/30/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

Both units acid/detergent cleaned.

213 7/1/82 Unit 1 Standby
Unit 2 Standby

214 7/2/82 Unit 1 Standby
Unit 2 Standby

215 7/3/82 Unit 1 Standby
Unit 2 Standby

216 7/4/82 Unit 1 Standby
Unit 2 Standby

217 7/5/82 Unit 1 Standby
Unit 2 Standby

218 7/6/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

Both units acid/detergent cleaned.

219 7/7/82 Unit 1 Sampling (1X)
Unit 2 Sampling (1X)

Both units acid/detergent cleaned. Two fuses blew on Variac-both replaced; Special intensity studies done.

220 7/8/82 Unit 1 Standby
Unit 2 Standby

221 7/9/82 Unit 1 Standby
Unit 2 Standby

222 7/10/82 Unit 1 Standby
Unit 2 Standby

223 7/11/82 Unit 1 Standby
Unit 2 Standby

224 7/12/82 Unit 1 Standby
Unit 2 Standby

Special intensity studies done. Air compressor serviced - air leak found at west end of Unit 1 cylinder - was repaired.

225 7/13/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

Second replicate series begun. Slight foaming in morning. Both units acid/detergent cleaned. Only 2 banks on for sampling.

226 7/14/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

Both unit acid/detergent cleaned. Two banks on for sampling.

227 7/15/82 Unit 1 Standby
Unit 2 Standby

Special intensity studies done.

228 7/16/82 Unit 1 Standby
Unit 2 Standby

229 7/17/82 Unit 1 Standby
Unit 2 Standby

230 7/18/82 Unit 1 Standby
Unit 2 Standby

231 7/19/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

Both units acid/detergent cleaned. Fuse blown over weekend. Two banks on for sampling.

232 7/20/82 Unit 1 Standby
Unit 2 Standby

233 7/21/82 Unit 1 Standby
Unit 2 Standby

Lithium study done - some foaming.

234 7/22/82 Unit 1
Unit 2

235 7/23/82 Unit 1
Unit 2

236 7/24/82 Unit 1
Unit 2

237 7/25/82 Unit 1
Unit 2

238 7/26/82 Unit 1
Unit 2

239 7/27/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

Both units acid/detergent cleaned. Serviced compressor - still runs constantly; probable leaks. Two banks on for sampling.

240 7/28/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

Both units acid/detergent cleaned. Two banks on for sampling. Compressor running constantly.

241 7/29/82 Unit 1 Sampling (1X)
Unit 2 Sampling (1X)

Both units acid/detergent cleaned. Two banks on for sampling.

242 7/30/82 Unit 1 Standby
Unit 2 Standby

243 7/31/82 Unit 1 Standby
Unit 2 Standby

244 8/1/82 Unit 1 Standby
Unit 2 Standby

245 8/2/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

Unit 1 has water leak during wiper stroke. Work begun on wiring on Unit 3. Both units acid detergent cleaned. Two banks on for sampling.

246 8/3/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

Foaming - severe at high flows. Both units acid detergent cleaned. Two banks on for sampling.

247 8/4/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

Unit 1 leaking through cable housing at east end of unit. Both units acid/detergent cleaned. Two banks on for sampling.

248 8/5/82 Unit 1 Standby
Unit 2 Standby

249 8/6/82 Unit 1 Standby
Unit 2 Standby

250 8/7/82 Unit 1 Standby
Unit 2 Standby

251 8/8/82 Unit 1 Standby
Unit 2 Standby

252 8/9/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

Both units acid/detergent cleaned. Two banks on for sampling. Unit 1 leaking from east side of wiper system - Recalibrated flumes - Unit 2 flowmeter way off - could not be calibrated - returned to lab. Twenty-four bulbs out in Unit 2. Excessive air leakage causing compressor to run constantly.

253 8/10/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

Both units acid/detergent cleaned. Two banks on for sampling. Spray water pump keeps kicking off - system shut down at end of day. Special intensity studies done.

254 8/11/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)

Both units acid/detergent cleaned. Two banks on for sampling.

255 8/12/82 Unit 1 Down
Unit 2 Down

PWS working on units (electrical). Unit 2 flow meter returned to plant, but could not be calibrated. Flowmeter returned to lab.

256 8/13/82 Unit 1 Down
Unit 2 Down

PWS took out 11 ballasts; 7 bad, 4 shorted.

257 8/14/82 Unit 1 Down
Unit 2 Down

258 8/15/82 Unit 1 Down
Unit 2 Down

259 8/16/82 Unit 1 Down
Unit 2 Down

PWS working on units. Unit 1 wiper cable replaced, air cylinder cleaned and air seal replaced.

260 8/17/82 Unit 1 Sampling (2X)
Unit 2 Down

Both units acid/detergent cleaned. Two banks on for sampling. Unit 2 ballasts smoking - unit shut down - no sampling.

261 8/18/82 Unit 1 Down
Unit 2 Down

Work on Unit 3 completed - left on overnight - leaks at influent end. Both PWS units shut down - overheating.

262 8/19/82 Unit 1 Down
Unit 2 Down

Spray water pump shut off sometime overnight. Units shut down for weekend.

263 8/20/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

264 8/21/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

265 8/22/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

Units 1 and 2 kept shutdown; Startup of Unit 3!

266 8/23/82 Unit 1 Down
Unit 2 Down
Unit 3 Sampling (3X)

267 8/24/82 Unit 1 Down
Unit 2 Down
Unit 3 Sampling (3X)

PWS on site. Burning smell in shed several hours after PWS left-shutdown both Units 1 and 2. Leak in influent T getting worse - leaking into shed at foundation.

268 8/25/82 Unit 1 Down
Unit 2 Down
Unit 3 Sampling (3X)

Units 1 and 2 turned on - burning smell - shut off; notified PWS. Ten indicators out on Unit 3. Nineteen bulbs out in Unit 1, 2 in Unit 2.

269 8/26/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

All bulbs in Unit 3 but one came on when unit turned on.

270 8/27/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

271 8/28/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

272 8/29/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

273 8/30/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

Flanges on Unit 3 influent pipe tightened.

274 8/31/82 Unit 1 Down
Unit 2 Down
Unit 3 Sampling (1X)

Worked on intensity probes in Unit 3. PWS on site replace burned parts.

275 9/1/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Sampling (3X)

Compressor serviced, however, still runs continuously. Unit 2 shows evidence of further burning.

276 9/2/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

Unit 2 smells like its burning; same number of bulbs out as yesterday. Spray water pump keeps kicking out. Compressor running continuously - no severe air leaks found. Unit 2 flow meter installed. Units shut down for weekend.

277 9/3/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

278 9/4/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

279 9/5/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

280 9/6/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

281 9/7/82 Unit 1 Down
Unit 2 Down
Unit 3 Sampling (2X)

Units 1 and 2 both had fires shortly after being turned on. Both units will be shutdown until problem is resolved. Noticed that two banks of lamps were out in Unit 3 after second sampling. Spray water pump kept kicking out.

282 9/8/82 Unit 1 Down
Unit 2 Down
Unit 3 Sampling (3X)

Gate closed in Unit 3 to shut down flow to teflon tubes surrounded by bulbs that are off.

283 9/9/82 Unit 1 Down
Unit 2 Down
Unit 3 Standby

Lithium tracer study done on Unit 3.

284 9/10/82 Unit 1 Down
Unit 2 Down
Unit 3 Standby

285 9/11/82 Unit 1 Down
Unit 2 Down
Unit 3 Standby

286 9/12/82 Unit 1 Down
Unit 2 Down
Unit 3 Standby

287 9/13/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

Unit 3 shutdown for week. Time will be spent working on repairing leaks in plant piping and preparing to pull the Bypass pump pipe.

288 9/14/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

Braces cut on bypass pipe. Serviced spray water pump - runs smoother. PWS suspects ballasts oversized for lamps.

289 9/15/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

Pulled bypass pump suction pipe-found screen clogged.

290 9/16/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

Worked on bypass intake pipe and reset it in bypass channel. PWS lab work indicates there should be 4 lamps on each ballast.

291 9/17/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

292 9/18/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

293 9/19/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

294 9/20/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

PWS working on Unit 2. Removed Buss Bars for rewiring.

295 9/21/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

296 9/22/82 Unit 1 Down
Unit 2 Down
Unit 3 Sampling (1X)

Two breakers in Unit 3 tripped and would not go back on - burning smell. Unit shut down after first sample. Will not be started until problems are resolved.

297 9/23/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

298 9/24/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

299 9/25/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

300 9/26/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

301 9/27/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

302 9/28/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

303 9/29/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

PWS units rewiring completed - fully operational.

304 9/30/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

Worked on repairing leaks in piping.

305 10/1/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

306 10/2/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

307 10/3/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

308 10/4/82 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)
Unit 3 Down

Acid/detergent cleaned Units 1 and 2.

309 10/5/82 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)
Unit 3 Down

Flume meter lines cleaned IL 570 probe mount repaired. Some foaming at moderate and high flows.

310 10/6/82 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)
Unit 3 Down

Acid/detergent cleaned units 1 and 2. Foaming at high flows.

311 10/7/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

312 10/8/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

313 10/9/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

314 10/10/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

315 10/11/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

316 10/12/82 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)
Unit 3 Down

PWS units shut down in AM. Personnel from ENERCO (Teflon unit) on-site to discuss installation of a shed and repair of electrical meters.

317 10/13/82 Unit 1 Sampling (1X)
Unit 2 Sampling (1X)
Unit 3 Down

First primary effluent sampling.

318 10/14/82 Unit 1 Down
Unit 2 Standby
Unit 3 Down

319 10/15/82 Unit 1 Down
Unit 2 Standby
Unit 3 Down

PWS working on rewiring Unit 1. (will stay down till complete)

320 10/16/82 Unit 1 Down
Unit 2 Standby
Unit 3 Down

321 10/17/82 Unit 1 Down
Unit 2 Standby
Unit 3 Down

322 10/18/82 Unit 1 Down
Unit 2 Sampling (3X)
Unit 3 Down

Construction company working on shed for ENERCO unit. Personnel from ENERCO on site to service unit.

323 10/19/82 Unit 1 Down
Unit 2 Sampling (3X)
Unit 3 Down

324 10/20/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

PWS on site rewiring Unit 1. Main power had to be shut off therefore, no sampling. Shed for ENERCO unit completed.

325 10/21/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

326 10/22/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

Rewiring of ENERCO unit completed.

327 10/23/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

328 10/24/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

329 10/25/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)
Unit 3 Down

Both Units 1 and 2 acid/detergent cleaned. Primary effluent sampling today. Work being done on rewiring ENERCO unit.

330 10/26/82 Unit 1 Sampling (1X)
Unit 2 Sampling (1X)
Unit 3 Down

All lamps in ENERCO unit working. Work still needs to be done on metering. Lamps in ENERCO unit cleaned.

331 10/27/82 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)
Unit 3 Down

Acid/detergent cleaned Units 1 and 2. PWS lamp temperature probe broken.

332 10/28/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

333 10/29/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

334 10/30/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

335 10/31/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

336 11/1/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

337 11/2/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)
Unit 3 Down

Foaming at high flows. Units 1 and 2 acid/detergent cleaned.

338 11/3/82 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)
Unit 3 Down

Foaming at high flows. Units 1 and 2 acid/detergent cleaned.

339 11/4/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

Repaired air leak in cabinet of Unit 1.

340 11/5/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

341 11/6/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

342 11/7/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

343 11/8/82 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)
Unit 3 Down

Units 1 and 2 acid/detergent cleaned.

344 11/9/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

Unit 1 and 2 down in an attempt to control bugs (midges). Bulbs in Unit 3 cleaned and replaced.

345 11/10/82 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)
Unit 3 Down

Units 1 and 2 acid/detergent cleaned.

346 11/11/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

347 11/12/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

348 11/13/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

349 11/14/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

350 11/15/82 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)
Unit 3 Down

Began wiper study #1. Units 1 and 2 acid/detergent cleaned. Unit 2 wiper will be kept off. Only 2 banks will be on for sampling. ENERCO completed work on Unit 3 - waiting for electrician.

351 11/16/82 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)
Unit 3 Down

Foaming at high flows. Wiper study (#1 on; #2 off) continued. Two banks on for sampling.

352 11/17/82 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)
Unit 3 Down

Wiper study (# 1 on; # 2 off) continued. Two banks on for sampling.

353 11/18/82 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)
Unit 3 Down

Wiper study (# 1 on; # 2 off) continued. Two banks on for sampling. Electricians finished working on Unit 3.

354 11/19/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

Wiper Study (# 1 on; # 2 off) continued.

355 11/20/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

Wiper Study (# 1 on; # 2 off) continued.

356 11/21/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

Wiper Study (# 1 on; # 2 off) continued.

357 11/22/82 Unit 1 Sampling (1X)
Unit 2 Sampling (1X)
Unit 3 Sampling (3X)

Wiper Study (# 1 on; # 2 off) continued. Two banks on for sampling. Sampled Unit 3 for 1st time since September.

358 11/23/82 Unit 1 Sampling (1X)
Unit 2 Sampling (1X)
Unit 3 Sampling (3X)

Wiper Study (# 1 on; # 2 off) continued. Two banks on for sampling.

359 11/24/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

Wiper Study (# 1 on; # 2 off) continued.

360 11/25/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

Wiper Study (# 1 on; # 2 off) continued.

361 11/26/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

Wiper Study (# 1 on; # 2 off) continued.

362 11/27/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

Wiper Study (# 1 on; # 2 off) continued.

363 11/28/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

Wiper Study (# 1 on; # 2 off) continued.

364 11/29/82 Unit 1 Sampling (1X)
Unit 2 Sampling (1X)
Unit 3 Sampling (3X)

Started wiper study again. Acid/detergent cleaned units 1 and 2. Wiper # 1 on; Wiper # 2 off. All banks on for entire study.

365 11/30/82 Unit 1 Sampling (1X)
Unit 2 Sampling (1X)
Unit 3 Sampling (1X)

Wiper Study (# 1 on; wiper # 2 off) continued.

366 12/1/82 Unit 1 Sampling (1X)
Unit 2 Sampling (1X)
Unit 3 Sampling (1X)

Severe foaming at high flows. Wiper Study (# 1 on; # 2 off) continued.

367 12/2/82 Unit 1 Sampling (1X)
Unit 2 Sampling (1X)
Unit 3 Sampling (3X)

Wiper Study (# 1 on; # 2 off) continued.

368 12/3/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

Wiper Study (# 1 on; # 2 off) continued. Lithium studies done on Units 1 and 2. Unit 1 lamp temperature probe returned.

369 12/4/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

Wiper Study (# 1 on; # 2 off) continued.

370 12/5/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

Wiper Study (# 1 on; # 2 off) continued.

371 12/6/82 Unit 1 Down
Unit 2 Sampling (1X)
Unit 3 Sampling (3X)

Quartz tube broke in Unit 1 over weekend PWS notified. Wiper # 2 still off.

372 12/7/82 Unit 1 Down
Unit 2 Sampling (1X)
Unit 3 Sampling (3X)

Unit 2 wiper still off.

373 12/8/82 Unit 1 Down
Unit 2 Sampling (1X)
Unit 3 Sampling (3X)

Unit 2 wiper still off.

374 12/9/82 Unit 1 Down
Unit 2 Standby
Unit 3 Standby

Unit 2 wiper still off.

375 12/10/82 Unit 1 Down
Unit 2 Standby
Unit 3 Standby

Lithium tracer studies done on Unit 3. Unit 2 wiper still off.

376 12/11/82 Unit 1 Down
Unit 2 Standby
Unit 3 Standby

Unit 2 wiper still off.

377 12/12/82 Unit 1 Down
Unit 2 Standby
Unit 3 Standby

Unit 2 wiper still off.

378 12/13/82 Unit 1 Down
Unit 2 Sampling (1X)
Unit 3 Sampling (3X)

PWS working on Unit 1. Unit 2 wiper still off.

379 12/14/82 Unit 1 Down
Unit 2 Sampling (1X)
Unit 3 Sampling (3X)

Unit 1 repairs completed and tank cleaned out. Unit 2 wiper still off.

380 12/15/82 Unit 1 Sampling (1X)
Unit 2 Sampling (1X)
Unit 3 Sampling (1X)

Replaced burnt out lamps in Units 1 and 2. Six lamps in Unit 1 still don't light. Units 1 and 2 acid/detergent cleaned. Influent colored red. Several lamps out in Unit 3.

381 12/16/82 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)
Unit 3 Sampling (2X)

Primary effluent sampling (bypass pump in use)

382 12/17/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

Lithium tracer studies done

383 12/18/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

384 12/19/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

385 12/20/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Sampling (4X)

Breaker in Unit 3 kept tripping out - ENERCO notified. Looked at effect of acid cleaning on Unit 3 using one compartment.

386 12/21/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Sampling (2X)

Looked at effect of cleaning teflon tubes with snake. ENERCO repaired Unit 3. Foaming at end of day - Units shut down overnight.

387 12/22/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

Severe foaming

388 12/23/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

Foaming

389 12/24/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

Foaming

390 12/25/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

Foaming

391 12/26/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

Foaming

392 12/27/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

Foaming

393 12/28/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

Foaming

394 12/29/82 Unit 1 Down
Unit 2 Down
Unit 3 Down

Foaming

395 12/30/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

Units turned on - no longer foaming. Compressor serviced. Unit 3 breaker tripping out.

396 12/31/82 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

Lithium tracer studies done. Breaker keeps tripping out in Unit 3. ENERCO notified.

397 1/1/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

398 1/2/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

399 1/3/83 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)
Unit 3 Standby

Unit 3 breaker still tripping out - unit not sampled.

400 1/4/83 Unit 1 Sampling (1X)
Unit 2 Sampling (1X)
Unit 3 Sampling (1X)

Started wiper study on Units 1 and 2. Acid/detergent cleaned both units. Unit 1 wiper on, unit 2 wiper off. All banks on for entire study. ENERCO on site to replace breaker and loose wire in Unit 3. Looked at cleaning of teflon tubes.

401 1/5/83 Unit 1 Sampling (1X)
Unit 2 Sampling (1X)
Unit 3 Sampling (1X)

Wiper Study (# 1 on; # 2 off) continued.

402 1/6/83 Unit 1 Sampling (1X)
Unit 2 Sampling (1X)
Unit 3 Sampling (2X)

Wiper Study (# 1 on; # 2 off) continued. Looked at cleaning of teflon tubes. Compressor sounds bad. Noticed lamps in Unit 3 on at one sampling may be off at next, (likely is ballast - thermally cutting off).

403 1/7/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

Wiper Study (# 1 on; # 2 off) continued.

404 1/8/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

Wiper Study (# 1 on; # 2 off) continued.

405 1/9/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

Wiper Study (# 1 on; # 2 off) continued.

406 1/10/83 Unit 1 Sampling (1X)
Unit 2 Sampling (1X)
Unit 3 Sampling (1X)

Wiper Study (# 1 on; # 2 off) continued.

407 1/11/83 Unit 1 Sampling (1X)
Unit 2 Sampling (1X)
Unit 3 Sampling (1X)

Wiper Study (# 1 on; # 2 off) continued. Unit 3 fans turned on to see if they help solve bulb problems. IL 570 (recalibration) newly mounted - different distance from lamp.

408 1/12/83 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)
Unit 3 Standby

Acid/detergent cleaned Units 1 and 2. Both effluent tanks cleaned and flushed. Started another wiper study. Wiper # 1 on; Wiper # 2 off.

409 1/13/83 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)
Unit 3 Standby

Wiper Study (# 1 on; # 2 off) continued. Plant effluent quality poor. Repaired lamp temperature probe in Unit 1. Unit 2 flowmeter could not be calibrated returned to lab for servicing. Some foaming.

410 1/14/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

Wiper Study (# 1 on; # 2 off) continued. Lithium tracer studies done on Unit 3.

411 1/15/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

Wiper Study (# 1 on; # 2 off) continued.

412 1/16/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

Wiper Study (# 1 on; # 2 off) continued.

413 1/17/83 Unit 1 Sampling (1X)
Unit 2 Sampling (1X)
Unit 3 Sampling (1X)

Acid/detergent cleaned both units 1 and 2. Another wiper study started with wiper # 1 off and wiper # 2 on. All banks on for entire study. Cleaned one tube in Unit 3 - sampled that tube only (Tube 4).

414 1/18/83 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)
Unit 3 Sampling (1X)

Wiper study (# 1 off; # 2 on) continued. Unit 3 breakers keep tripping out. Sampled tube 4 only.

415 1/19/83 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)
Unit 3 Sampling (2X)

Wiper study (# 1 off; # 2 on) continued. Unit 3 sampled at tube 4 only.

416 1/20/83 Unit 1 Sampling (1X)
Unit 2 Sampling (1X)
Unit 3 Sampling (2X)

Wiper Study (# 1 off; # 2 on) continued. Unit 3 sampled at tube 4 only.

417 1/21/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

Wiper Study (# 1 off; # 2 on) continued.

418 1/22/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

Wiper Study (# 1 off; # 2 on) continued.

419 1/23/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

Wiper Study (# 1 off; # 2 on) continued.

420 1/24/83 Unit 1 Sampling (1X)
Unit 2 Sampling (1X)
Unit 3 Down

Wiper Study (# 1 off; # 2 on) continued. First breaker in Unit 3 still tripping out.

421 1/25/83 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)
Unit 3 Sampling (3X)

Wiper Study (# 1 off; # 2 on) continued. Unit 3 breaker okay today. Sampled at tube 4 only.

422 1/26/83 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)
Unit 3 Sampling (1X)

Wiper Study (# 1 off; # 2 on) concluded after first sampling. Unit 1 and 2 acid cleaned twice before second sampling (both wipers on). Foaming. Plant effluent quality poor.

423 1/27/83 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)
Unit 3 Sampling (2X)

Unit 3 breaker tripping out.

424 1/28/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

425 1/29/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

426 1/30/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

427 1/31/83 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)
Unit 3 Down

Units 1 and 2 acid/detergent cleaned before first sample. Unit 3 down until repairs completed.

428 2/1/83 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)
Unit 3 Down

429 2/2/83 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)
Unit 3 Down

Units 1 and 2 acid/detergent cleaned before first sampling.

430 2/3/83 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)
Unit 3 Down

Units 1 and 2 acid/detergent cleaned before first sampling. ENERCO on site working on teflon tubes.

431 2/4/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

432 2/5/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

433 2/6/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

434 2/7/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

435 2/8/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

436 2/9/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

Units 1 and 2 dismantled for complete cleaning. (bulbs & quartz tubes)

437 2/10/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

Completion of cleaning of units 1 and 2. Sludge cleaned out of effluent tanks of Units 1 and 2. Units on standby for weekend.

438 2/11/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

439 2/12/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

440 2/13/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

441 2/14/83 Unit 1 Sampling (1X)
Unit 2 Sampling (1X)
Unit 3 Down

Digout from Blizzard of 1983. Units 1 and 2 acid/detergent cleaned before first sample. Spray water pump sounds very bad - needs servicing soon.

442 2/15/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

443 2/16/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

444	2/17/83	Unit 1	Sampling (2X)
		Unit 2	Sampling (2X)
		Unit 3	Down
445	2/18/83	Unit 1	Standby
		Unit 2	Standby
		Unit 3	Down
446	2/19/83	Unit 1	Standby
		Unit 2	Standby
		Unit 3	Down
447	2/20/83	Unit 1	Standby
		Unit 2	Standby
		Unit 3	Down
448	2/21/83	Unit 1	Standby
		Unit 2	Standby
		Unit 3	Down
449	2/22/83	Unit 1	Down
		Unit 2	Down
		Unit 3	Down

Unit 1 and 2 down for spray water pump servicing

450	2/23/83	Unit 1	Standby
		Unit 2	Standby
		Unit 3	Down
451	2/24/83	Unit 1	Standby
		Unit 2	Standby
		Unit 3	Down
452	2/25/83	Unit 1	Standby
		Unit 2	Standby
		Unit 3	Down
453	2/26/83	Unit 1	Standby
		Unit 2	Standby
		Unit 3	Down
454	2/27/83	Unit 1	Standby
		Unit 2	Standby
		Unit 3	Down
455	2/28/83	Unit 1	Sampling (2X)
		Unit 2	Sampling (2X)
		Unit 3	Down

Units 1 and 2 acid/detergent cleaned before first sampling. Unit 1 flowmeter not working. Unit 2 flowmeter at ISCO for repairs.

456 3/1/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

457 3/2/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

Severe foaming. Flow to Units 1 and 2 as low as possible.

458 3/3/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

Foaming

459 3/4/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

Foaming

460 3/5/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

461 3/6/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

462 3/7/83 Unit 1 Down
Unit 2 Sampling (3X)
Unit 3 Down

Unit 1 wiper cable broke over weekend. Unit 2 acid/detergent cleaned before first sampling.

463 3/8/83 Unit 1 Down
Unit 2 Sampling (3X)
Unit 3 Down

PWS and ENERCO personnel on site. Unit 2 acid/detergent cleaned before first sampling. Plant bypassing in afternoon, last sample is primary effluent.

464 3/9/83 Unit 1 Down
Unit 2 Sampling (3X)
Unit 3 Down

PWS finished work on Unit 1 wiper cable. Unit 2 acid/detergent cleaned before first sampling. Some foaming.

465 3/10/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

466 3/11/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

467 3/12/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

468 3/13/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

469 3/14/83 Unit 1 Down
Unit 2 Sampling (2X)
Unit 3 Sampling (2X)

Unit 2 acid/detergent cleaned before first sampling. Severe air leaks in Unit 1. PWS notified. Work completed on Unit 3 - all flow through one channel. Air compressor belt tightened.

470 3/15/83 Unit 1 Down
Unit 2 Sampling (2X)
Unit 3 Sampling (2X)

Unit 2 acid/detergent cleaned before first sampling PWS on site - wiper cable just installed failed and must be replaced. Unit 3 all flow through one channel.

471 3/16/83 Unit 1 Down
Unit 2 Sampling (2X)
Unit 3 Sampling (2X)

Unit 2 acid/detergent cleaned before first sampling. Unit 3 all flow through one channel.

472 3/17/83 Unit 1 Down
Unit 2 Sampling (2X)
Unit 3 Sampling (2X)

Unit 2 acid/detergent cleaned before first sampling. PWS on site finished work on Unit 1.
Unit 3 all flow through one channel.

473 3/18/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

444	2/17/83	Unit 1	Sampling (2X)
		Unit 2	Sampling (2X)
		Unit 3	Down
445	2/18/83	Unit 1	Standby
		Unit 2	Standby
		Unit 3	Down
446	2/19/83	Unit 1	Standby
		Unit 2	Standby
		Unit 3	Down
447	2/20/83	Unit 1	Standby
		Unit 2	Standby
		Unit 3	Down
448	2/21/83	Unit 1	Standby
		Unit 2	Standby
		Unit 3	Down
449	2/22/83	Unit 1	Down
		Unit 2	Down
		Unit 3	Down
		Unit 1 and 2 down for spray water pump servicing	
450	2/23/83	Unit 1	Standby
		Unit 2	Standby
		Unit 3	Down
451	2/24/83	Unit 1	Standby
		Unit 2	Standby
		Unit 3	Down
452	2/25/83	Unit 1	Standby
		Unit 2	Standby
		Unit 3	Down
453	2/26/83	Unit 1	Standby
		Unit 2	Standby
		Unit 3	Down
454	2/27/83	Unit 1	Standby
		Unit 2	Standby
		Unit 3	Down
455	2/28/83	Unit 1	Sampling (2X)
		Unit 2	Sampling (2X)
		Unit 3	Down
		Units 1 and 2 acid/detergent cleaned before first sampling. Unit 1 flowmeter not working. Unit 2 flowmeter at ISCO for repairs.	

456 3/1/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

457 3/2/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

Severe foaming. Flow to Units 1 and 2 as low as possible.

458 3/3/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

Foaming

459 3/4/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

Foaming

460 3/5/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

461 3/6/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

462 3/7/83 Unit 1 Down
Unit 2 Sampling (3X)
Unit 3 Down

Unit 1 wiper cable broke over weekend. Unit 2 acid/detergent cleaned before first sampling.

463 3/8/83 Unit 1 Down
Unit 2 Sampling (3X)
Unit 3 Down

PWS and ENERCO personnel on site. Unit 2 acid/detergent cleaned before first sampling. Plant bypassing in afternoon, last sample is primary effluent.

464 3/9/83 Unit 1 Down
Unit 2 Sampling (3X)
Unit 3 Down

PWS finished work on Unit 1 wiper cable. Unit 2 acid/detergent cleaned before first sampling. Some foaming.

465 3/10/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

466 3/11/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

467 3/12/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

468 3/13/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

469 3/14/83 Unit 1 Down
Unit 2 Sampling (2X)
Unit 3 Sampling (2X)

Unit 2 acid/detergent cleaned before first sampling. Severe air leaks in Unit 1. PWS notified. Work completed on Unit 3 - all flow through one channel. Air compressor belt tightened.

470 3/15/83 Unit 1 Down
Unit 2 Sampling (2X)
Unit 3 Sampling (2X)

Unit 2 acid/detergent cleaned before first sampling PWS on site - wiper cable just installed failed and must be replaced. Unit 3 all flow through one channel.

471 3/16/83 Unit 1 Down
Unit 2 Sampling (2X)
Unit 3 Sampling (2X)

Unit 2 acid/detergent cleaned before first sampling. Unit 3 all flow through one channel.

472 3/17/83 Unit 1 Down
Unit 2 Sampling (2X)
Unit 3 Sampling (2X)

Unit 2 acid/detergent cleaned before first sampling. PWS on site finished work on Unit 1.
Unit 3 all flow through one channel.

473 3/18/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

474 3/19/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

475 3/20/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

476 3/21/83 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)
Unit 3 Sampling (2X)

All sampling on primary effluent. Units 1 and 2 both acid/detergent cleaned. All flow in Unit 3 through one channel. Inline spectrophotometer arrived, however, was damaged in transit. General Atomic on site working to install spectrophotometer in Unit 1 - not working.

477 3/22/83 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)
Unit 3 Sampling (2X)

Work continued on spectrophotometer. Flow in Unit 3 through 3 channels. Exit bank of lamps off in both Units 1 and 2.

478 3/23/83 Unit 1 Sampling (1X)
Unit 2 Sampling (1X)
Unit 3 Sampling (1X)

Units 1 and 2 both acid/detergent cleaned. Exit bank of lamps off in both Units 1 and 2. Air compressor serviced - minor air leak in Unit 1. Flow in Unit 3 through 3 channels. Inline spectrophotometer installation completed.

479 3/24/83 Unit 1 Sampling (1X)
Unit 2 Sampling (1X)
Unit 3 Sampling (1X)

Exit bank of lamps off in both Units 1 and 2. Some foaming especially at high flows. Flow in Unit 3 through 3 channels.

480 3/25/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

481 3/26/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

482 3/27/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

483 3/28/83 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)
Unit 3 Sampling (2X)

Units 1 and 2 acid/detergent cleaned. Exit bank of lamps off in both Units 1 and 2. Unit 1 still leaking air from wiper system. Flow in Unit 3 through 1 channel. Unit 3 voltage at 65%.

484 3/29/83 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)
Unit 3 Sampling (2X)

Units 1 and 2 both acid/detergent cleaned. Three banks of lamps on in Units 1 and 2 for first sampling - 2 banks on for second sampling - Unit 3 voltage at 65% for 1st sampling - changed to 100% for 2nd sampling. Unit 3 flow through one channel. Inline spectrophotometer not working.

485 3/30/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

486 3/31/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

487 4/1/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

488 4/2/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

489 4/3/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

490 4/4/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

491 4/5/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

492 4/6/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

493 4/7/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

494 4/8/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

495 4/9/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

496 4/10/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

497 4/11/83 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)
Unit 3 Standby

Beginning of replicate series. Unit 1 and 2 both acid/detergent cleaned. Exit banks off in both units for sampling. Severe air leak from compressor head - compressor running constantly. PWS notified.

498 4/12/83 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)
Unit 3 Standby

Continuation of replicate series. Units 1 and 2 both acid/detergent cleaned. Exit banks off in both units for sampling. Compressor still running constantly.

499 4/13/83 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)
Unit 3 Standby

Continuation of replicate series. Units 1 and 2 both acid/detergent cleaned. Exit banks off in both units for sampling. Noticed unit 2 wiper not traveling over entire length of bulb - maybe related to compressor problem.

500 4/14/83 Unit 1 Down
Unit 2 Down
Unit 3 Sampling (6X)

Gasket for compressor arrived. Took compressor apart and found a broken valve, tried to locate part without success. Unit 3 flow through 1 channnel.

501 4/15/83 Unit 1 Down
Unit 2 Down
Unit 3 Standby

502 4/16/83 Unit 1 Down
Unit 2 Down
Unit 3 Standby

503 4/17/83 Unit 1 Down
Unit 2 Down
Unit 3 Standby

504 4/18/83 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)
Unit 3 Standby

Replicate series continued. Units 1 and 2 both acid/detergent cleaned. Exit banks off in both units for sampling. Compressor repaired and is working well. Unit 2 wiper still not traveling entire length of bulb.

505 4/19/83 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)
Unit 3 Standby

Continuation of replicate series. Units 1 and 2 both acid/detergent cleaned. Exit banks off in both units for sampling. Still have problem with Unit 2 wiper - PWS notified. Tried to calibrate flumes - Unit 2 meter works okay but Unit 1 meter drifts badly.

506 4/20/83 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)
Unit 3 Standby

Continuation of replicate series. Units 1 and 2 both acid/detergent cleaned. Exit banks off in both units for sampling. Still have problem with Unit 2 wiper.

507 4/21/83 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)
Unit 3 Sampling (6X)

Continuation of replicate series. Units 1 and 2 both acid/detergent cleaned. Exit banks off in both units for sampling. Still have problem with Unit 2 wiper. Unit 3 flow all through 1 channel.

508 4/22/83 Unit 1 Standby
Unit 2 Down
Unit 3 Standby

Unit 2 leaking at buss bar.

509 4/23/83 Unit 1 Standby
Unit 2 Down
Unit 3 Standby

510 4/24/83 Unit 1 Standby
Unit 2 Down
Unit 3 Standby

511 4/25/83 Unit 1 Down
Unit 2 Down
Unit 3 Sampling (3X)

Compressor not working properly - not enough pressure to move wipers - appears to be leaking at head gasket. PWS notified. Unit 3 flow all through 1 channel.

512 4/26/83 Unit 1 Down
Unit 2 Down
Unit 3 Sampling (3X)

PWS on site. Unit 2 needs another wiper cable. Unit 3 flow all through 1 channel.

513 4/27/83 Unit 1 Down
Unit 2 Down
Unit 3 Sampling (3X)

PWS on site. Resealed wiper mechanism on Unit 2. Unit 3 flow all through one channel.

514 4/28/83 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)
Unit 3 Standby

Continuation of replicate series. Units 1 and 2 both acid/detergent cleaned. Exit banks off in both units for sampling. Compressor blew head gasket - needs new head. Noted wipers failing so all 3 samples taken in 1 1/2 hours. Compressor turned off for weekend.

515 4/29/83 Unit 1 Down
Unit 2 Down
Unit 3 Standby

516 4/30/83 Unit 1 Down
Unit 2 Down
Unit 3 Standby

517 5/1/83 Unit 1 Down
Unit 2 Down
Unit 3 Standby

518 5/2/83 Unit 1 Down
Unit 2 Down
Unit 3 Standby

519 5/3/83 Unit 1 Down
Unit 2 Down
Unit 3 Standby

520 5/4/83 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)
Unit 3 Standby

Continuation of replicate series. Units 1 and 2 both acid/detergent cleaned. Exit banks off in both units for sampling. Spray water pump went off sometime since Thursday, therefore, no flow to units - tanks black. Compressor head replaced.

521 5/5/83 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)
Unit 3 Standby

Continuation of replicate series. Units 1 and 2 both acid/detergent cleaned. Exit banks off in both units for sampling. Spray water pump shut off during day.

522 5/6/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

University of North Carolina personnel on site to do bioassay work over weekend.

523 5/7/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

524 5/8/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

525 5/9/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

526 5/10/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

Dose-response study done in lab.

527 5/11/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

Units shut down until start up of extension period. Bearings in spray water pump need replacing. Primary effluent pump turned on to have flow through units. Several arc studies done.

528 5/12/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

529 5/13/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

Primary effluent bypass pump turned off - not working properly - bad bearings.

530 5/14/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

531 5/15/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

532 5/16/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

533 5/17/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

Unit 3 flushed out with garden hose. Effluent tanks of Units 1 and 2 black.

534 5/18/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

535 5/19/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

536 5/20/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

537 5/21/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

538 5/22/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

539 5/23/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

Attempted to set up ballast and bulbs outside of Unit 1 to do special studies - unit burnt out. PWS notified. Primary effluent bypass pump turned on for short time in an attempt to flush out tanks.

540 5/24/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

Lamp temperature probe taken to PWS for servicing - needs new sensor. PWS made set up so can do special studies outside of unit wiring. Began checking intensity at one point on all lamps in Units 1 and 2. Lamps numbered as checked out.

541 5/25/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

Continued checking intensity of lamps in Units 1 and 2

542 5/26/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

550 6/3/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

551 6/4/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

552 6/5/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

553 6/6/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

Continuation of cleaning lamps and insides of quartz sleeves. Several arc studies done.

554 6/7/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

555	6/8/83	Unit 1	Down
		Unit 2	Down
		Unit 3	Down
556	6/9/83	Unit 1	Down
		Unit 2	Down
		Unit 3	Down
557	6/10/83	Unit 1	Down
		Unit 2	Down
		Unit 3	Down
558	6/11/83	Unit 1	Down
		Unit 2	Down
		Unit 3	Down
559	6/12/83	Unit 1	Down
		Unit 2	Down
		Unit 3	Down
560	6/13/83	Unit 1	Down
		Unit 2	Down
		Unit 3	Down
561	6/14/83	Unit 1	Down
		Unit 2	Down
		Unit 3	Down
562	6/15/83	Unit 1	Down
		Unit 2	Down
		Unit 3	Down
563	6/16/83	Unit 1	Down
		Unit 2	Down
		Unit 3	Down
564	6/17/83	Unit 1	Down
		Unit 2	Down
		Unit 3	Down
565	6/18/83	Unit 1	Down
		Unit 2	Down
		Unit 3	Down
566	6/19/83	Unit 1	Down
		Unit 2	Down
		Unit 3	Down
567	6/20/83	Unit 1	Down
		Unit 2	Down
		Unit 3	Down

Unit 3 turned on and control box on outside of unit exploded. ENERCO notified.

568 6/21/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

569 6/22/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

570 6/23/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

571 6/24/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

572 6/25/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

573 6/26/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

574 6/27/83 Unit 1 Down
Unit 2 Down
Unit 3 Sampling (3X)

Flow in Unit 3 through 1 channel. Spray water pump keeps shutting down.

575 6/28/83 Unit 1 Down
Unit 2 Down
Unit 3 Sampling (3X)

Flow in Unit 3 through 1 channel. First breaker in Unit 3 tripped and would not stay reset. Lamps out that affected channel 1 came on during day. Plant electrician checked spray water pump and recommended that the breaker door be left open.

576 6/29/83 Unit 1 Down
Unit 2 Down
Unit 3 Sampling (3X)

Flow in Unit 3 through 1 channel. Lamps in Unit 3 still going on and off. Photoreactivation studies done.

577 6/30/83 Unit 1 Down
Unit 2 Down
Unit 3 Sampling (3X)

Flow in Unit 3 though 1 channel. Lamps in Unit 3 working sporadically. General Atomic personnel on site to service flow thru spectrophotometer.

578 7/1/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

579 7/2/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

580 7/3/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

581 7/4/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

582 7/5/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

Began work on installing new lamps in Units 1 and 2.

583 7/6/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

Continued working on lamp installation.

584 7/7/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

Finished installing new lamps. Exit bank in Units 1 and 2 not operational.

585 7/8/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

586 7/9/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

587 7/10/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

588 7/11/83 Unit 1 Down
Unit 2 Down
Unit 3 Down

589 7/12/83 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)
Unit 3 Down

Units 1 and 2 started up in the morning. Both units acid/detergent cleaned before first sampling. One bank on in each Unit for sampling.

590 7/13/83 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)
Unit 3 Down

Units 1 and 2 both acid/detergent cleaned before first sampling. One bank on in each unit for sampling. Spray water pump off in morning (control panel door had been closed).

591 7/14/83 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)
Unit 3 Down

Units 1 and 2 both acid/detergent cleaned before first sampling. One bank on in each unit for sampling. Spray water pump off in morning. Units shut down after last sample.

592 7/15/83 Unit 1 Down
Unit 2 Down
Unit 3 Down/Standby

ENERCO on-site all lamps now operating.

593 7/16/83 Unit 1 Down
Unit 2 Down
Unit 3 Standby

594 7/17/83 Unit 1 Down
Unit 2 Down
Unit 3 Standby

595 7/18/83 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)
Unit 3 Standby

Units 1 and 2 both acid/detergent cleaned before first sampling. Two banks on for sampling.

596 7/19/83 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)
Unit 3 Standby

Units 1 & 2 both acid/detergent cleaned before first sampling. Two banks on for sampling. Plant had some type of dump last night-strong petroleum odor.

597 7/20/83 Unit 1 Sampling (1X)
Unit 2 Sampling (1X)
Unit 3 Standby

Units 1 & 2 both acid/detergent cleaned before first sampling. Two banks on for sampling. Spill still very strong-oily scum in units-inline spectrophotometer readings 15 to 20 times normal.

598 7/21/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

Spill still affecting units. Influent is brown. Arc studies done on several new lamps.

599 7/22/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

600 7/23/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

601 7/24/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Standby

602 7/25/83 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)
Unit 3 Down/Standby

Units 1 and 2 both acid/detergent cleaned before first sampling. Two banks on for sampling. Unit 2 leaking. Inline spectrophotometer not working. ENERCO on-site to pressure clean teflon tubes. Unit 3 restarted after cleaning. Some foaming at effluent channel.

603 7/26/83 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)
Unit 3 Standby

Units 1 and 2 both acid/detergent cleaned before first sampling. Two banks on for sampling. Photoreactivation studies done. Foaming at effluent channel and in units at high flows.

604 7/27/93 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)
Unit 3 Standby

Units 1 and 2 both acid/detergent cleaned before first sampling. Two banks on for sampling. Photoreactivation studies done. Some foaming at effluent channel.

605 7/28/83 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)
Unit 3 Sampling (3X)

Units 1 and 2 both acid/detergent cleaned before first sampling. Two banks on for sampling. All flow in Unit 3 through one channel. First breaker in Unit 3 would not stay on. ENERCO notified. Severe foaming at effluent channel.

606 7/29/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

607 7/30/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

608 7/31/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

609 8/1/83 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)
Unit 3 Down

Units 1 and 2 both acid/detergent cleaned before first sampling. Two banks on for sampling. In line spectrophotometer still not working.

6/10 8/2/83 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)
Unit 3 Down

Units 1 and 2 both acid/detergent cleaned before first sampling. Two banks on for sampling. Photoreactivation study done on one sampling.

611 8/3/83 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)
Unit 3 Down

Units 1 and 2 both acid/detergent cleaned before first sampling. Two banks on for sampling. Photoreactivation study done on one sampling.

612 8/4/83 Unit 1 Sampling (3X)
Unit 2 Sampling (3X)
Unit 3 Down

Units 1 and 2 both acid/detergent cleaned before first sampling. Two banks on for sampling. Photoreactivation study done on one sampling. Severe foaming in afternoon. Flow shut down before leaving.

613 8/5/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

Foaming less severe - flow turned back on.

614 8/6/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

615 8/7/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Down

616 8/8/83 Unit 1 Sampling (3X)
Unit 2 Down
Unit 3 Down

Unit 1 acid/detergent cleaned before first sampling. Two banks on for sampling. Photoreactivation study done on each sampling. Unit 2 wiper not working. PWS notified.

617 8/9/83 Unit 1 Sampling (3X)
Unit 2 Down
Unit 3 Down

Unit 1 acid/detergent cleaned before first sampling. Two banks on for sampling. Photoreactivation study done on each sampling. PWS on site to service Unit 2 wiper-took piston to be cleaned - should return tomorrow.

618 8/10/83 Unit 1 Sampling (3X)
Unit 2 Down
Unit 3 Down

Unit 1 acid/detergent cleaned before first sampling. Two banks on for sampling.

619 8/11/83 Unit 1 Sampling (3X)
Unit 2 Down
Unit 3 Down

Unit 1 acid/detergent cleaned before first sampling. Two banks on for sampling. Photoreactivation study done on each sampling.

620 8/12/83 Unit 1 Standby
Unit 2 Down
Unit 3 Standby

ENERCO on site to repair unit.

621 8/13/83 Unit 1 Standby
Unit 2 Down
Unit 3 Standby

622 8/14/83 Unit 1 Standby
Unit 2 Down
Unit 3 Standby

623 8/15/83 Unit 1 Standby
Unit 2 Down
Unit 3 Standby

Personnel from University of North Carolina on site for the week.

624 8/16/83 Unit 1 Standby
Unit 2 Down
Unit 3 Standby

625 8/17/83 Unit 1 Standby
Unit 2 Down
Unit 3 Standby

626 8/18/83 Unit 1 Standby
Unit 2 Down
Unit 3 Standby

627 8/19/83 Unit 1 Standby
Unit 2 Down
Unit 3 Standby

628 8/20/83 Unit 1 Standby
Unit 2 Down
Unit 3 Standby

629 8/21/83 Unit 1 Standby
Unit 2 Down
Unit 3 Standby

619 8/11/83 Unit 1 Sampling (3X)
Unit 2 Down
Unit 3 Down

Unit 1 acid/detergent cleaned before first sampling. Two banks on for sampling. Photoreactivation study done on each sampling.

620 8/12/83 Unit 1 Standby
Unit 2 Down
Unit 3 Standby

ENERCO on site to repair unit.

621 8/13/83 Unit 1 Standby
Unit 2 Down
Unit 3 Standby

622 8/14/83 Unit 1 Standby
Unit 2 Down
Unit 3 Standby

623 8/15/83 Unit 1 Standby
Unit 2 Down
Unit 3 Standby

Personnel from University of North Carolina on site for the week.

624 8/16/83 Unit 1 Standby
Unit 2 Down
Unit 3 Standby

625 8/17/83 Unit 1 Standby
Unit 2 Down
Unit 3 Standby

626 8/18/83 Unit 1 Standby
Unit 2 Down
Unit 3 Standby

627 8/19/83 Unit 1 Standby
Unit 2 Down
Unit 3 Standby

628 8/20/83 Unit 1 Standby
Unit 2 Down
Unit 3 Standby

629 8/21/83 Unit 1 Standby
Unit 2 Down
Unit 3 Standby

630 8/22/83 Unit 1 Standby
Unit 2 Down
Unit 3 Sampling (2X)

Unit 3 flow through 1 channel. Bulbs operating sporadically-bulbs on for one sampling may be off for next.

631 8/23/83 Unit 1 Standby
Unit 2 Down
Unit 3 Sampling (2X)

Unit 3 flow through 1 channel. Bulbs operated okay. People from North Carolina finished up work today.

632 8/24/83 Unit 1 Standby
Unit 2 Down
Unit 3 Sampling (2X)

Unit 3 flow through 1 channel. Bulbs operated okay. Last sampling of Unit 3.

633 8/25/83 Unit 1 Sampling (2X)
Unit 2 Down
Unit 3 Down/off

Unit 1 acid/detergent cleaned. Two banks on for sampling. Several dose/response studies done in the lab. PWS on site to work on Unit 2 - will return tomorrow to finish. Unit 3 shut down.

634 8/26/83 Unit 1 Standby
Unit 2 Down/Standby
Unit 3 Off

635 8/27/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Off

636 8/28/83 Unit 1 Standby
Unit 2 Standby
Unit 3 Off

637 8/29/83 Unit 1 Sampling (2X)
Unit 2 Sampling (2X)
Unit 3 Off

Both units acid/detergent cleaned. Two banks on for sampling. Lamps PWS had taken out of Unit 2 were not returned to same positions. Some new lamps were put in bank that wasn't being used. Spent morning repositioning lamps. Several had been broken.

638 8/30/83 Unit 1 Sampling (6X)
Unit 2 Down
Unit 3 Off

Unit 1 acid/detergent cleaned. Two banks on for sampling. Broken quartz in Unit 2. Repaired by end of day. Primary effluent sampled.

639 8/31/83 Unit 1 Sampling (4X)
Unit 2 Sampling (4X)
Unit 3 Off

Both units acid/detergent cleaned. Two banks on for sampling. Unit 2 turned back on. Primary effluent sampled.

640 9/1/83 Unit 1 Sampling (4X)
Unit 2 Sampling (4X)/Down
Unit 3 Off

Both units acid/detergent cleaned. Two banks on for sampling. Primary effluent sampled. Unit 2 had a leak in bank that is off. Lamps shut off for weekend.

641 9/2/83 Unit 1 Standby
Unit 2 Down
Unit 3 Off

642 9/3/83 Unit 1 Standby
Unit 2 Down
Unit 3 Off

643 9/4/83 Unit 1 Standby
Unit 2 Down
Unit 3 Off

644 9/5/83 Unit 1 Standby
Unit 2 Down
Unit 3 Off

645 9/6/83 Unit 1 Sampling (4X)
Unit 2 Sampling (4X)
Unit 3 Off

Both units acid/detergent cleaned. Two banks on for sampling. Primary effluent sampled.

646 9/7/83 Unit 1 Sampling (4X)
Unit 2 Sampling (4X)
Unit 3 Off

Both units acid/detergent cleaned. Two banks on for sampling. Primary effluent sampled.

647 9/8/83 Unit 1 Sampling (4X)
Unit 2 Sampling (4X)
Unit 3 Off

Both units acid/detergent cleaned. Two banks on for sampling. Primary effluent sampled. Last day for sampling.

648 9/9/83 Unit 1 Standby
Unit 2 Down
Unit 3 Off

Unit 2 shut down because of leaking quartz.

649 9/10/83 Unit 1 Standby
Unit 2 Down
Unit 3 Off

650 9/11/83 Unit 1 Standby
Unit 2 Down
Unit 3 Off

651 9/12/83 Unit 1 Off
Unit 2 Off
Unit 3 Off

Units 1 and 2 shut down and tanks emptied. Began work on checking lamp intensities.

652 9/13/83 Unit 1 Off
Unit 2 Off
Unit 3 Off

Continuation of work on lamp intensities

653 9/14/83 Unit 1 Off
Unit 2 Off
Unit 3 Off

Continued work on lamp intensities and began picking up equipment.

654 9/15/83 Unit 1 Off
Unit 2 Off
Unit 3 Off

Continued work on lamp intensities and continued picking up equipment.

655 9/16/83 Unit 1 Off
Unit 2 Off
Unit 3 Off

Continued work on lamp intensities and packing equipment. Finish lamp studies next week in lab. End of on-site activities.

APPENDIX B
PORT RICHMOND FIELD DATA

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INTRODUCTION

This appendix presents the field data collected at New York City's Port Richmond Water Pollution Control Plant during the approximately 21 month UV disinfection pilot scale investigation. A discussion of the experimental program is presented in Sections 5 and 7 of this report. The data base editing is also discussed in Section 7. This appendix presents only those data considered acceptable for subsequent analysis.

The parameters in each table are explained prior to the presentation of the tables to ensure proper interpretation of the data.

DESCRIPTION OF DATA TABULATIONS

The data are separated into tables based on the information presented and the unit being reported on. The table of daily operating information (Table 1) presents the general conditions for each sampling day. The influent data to the UV units (secondary effluent) were divided into three tables. The operating conditions of both the widely spaced and closely spaced quartz units (Units 1 and 2, respectively) and the teflon unit (Unit 3) have been tabulated. A separate tabulation of each of the three UV system effluents is then presented.

The influent and effluent data from the sampling of primary effluent are presented separate from the routine data associated with the plant secondary effluent. The operating conditions for these samplings are not listed separately.

The first three columns, CODE, DATE, and TIME are common to all tables, unless otherwise stated. For convenience, these are described only once, as follows:

Code: A six digit code identifies each sampling. The first three digits of the code are the day number and the last three are the sampling number. The days were numbered consecutively beginning with day 001 on December 1, 1981 and ending with day 647 on September 8, 1983. The samplings were also numbered consecutively beginning with the first sampling (001) on December 2, 1981 and ending with sampling 513 on September 8, 1983.

Date: The date corresponds to the day number recorded in the first column.

Time: The time of each sampling was recorded in military time. A blank indicates that the sample time was not reported. If a sample was a primary effluent sample, this is indicated by "CSO" in this column.

Table 1. Daily Operating Conditions

Table 1 presents the daily conditions which existed on each sampling day. Each parameter recorded is discussed below under the heading as it appears in the table.

CODE DAY NO

The days were numbered consecutively beginning with day 001 on December 1, 1981 and ending with day 647 on September 8, 1983. Entries were made on this table for each day sampling was accomplished.

INF TEMP (C)

The influent temperature was measured and recorded in degrees Celsius (°C) once each sampling day. If no influent temperature was recorded asterisks (*) appear in this column.

AIR TEMP (°C)

The air temperature was recorded in degrees Celsius (°C) once each sampling day. If no air temperature was reported, asterisks (*) appear in this column.

POWER (kW-hr)

The kilowatt-hours (kW-hr) consumed by the two quartz systems (Unit 3 was not monitored for power) was read off the power meter and recorded once per sampling day. A blank indicates no power meter reading was taken.

POWER TIME

The time of the daily power meter reading was recorded in military time. This column is blank if no power meter reading was made or if the time was not reported.

Table 2. Influent (Secondary) to UV Units-Water Quality and Bacteriology

Table 2 presents a number of the parameters routinely measured on the influent to the UV units. The influent is the effluent from the Port Richmond secondary treatment plant. Each parameter is discussed below under the heading as it appears on the table. If an analysis was not performed on a sample a series of asterisks (*) appear in that column.

All influent samples were grabs taken from the influent tank of one of the UV units.

TURBIDITY (NTU)

Turbidity measurements were made on each influent sample for the entire length of the experimental program. Turbidity was measured with an Hach HF Turbidity Meter and recorded in nephelometric turbidity units (NTU). The meter was calibrated with prepared standards at each use.

SS (MG/L)

The influent suspended solids (SS) were determined on all samples during the entire experimental program. Gelman A/E glass fiber filter pads were used for the filtrations and the residue was dried at 103°C.

pH

The influent pH was monitored during the entire study using a Corning pH meter with a Ross combination electrode. The meter was calibrated at each use.

TOTAL COLIFORM (COL/100 ML)

The influent total coliform density was determined for each sample. The USEPA single step membrane filter (MF) procedure was followed. All plates were set within two hours after sampling. Four dilutions were routinely set for all samples. Starting in May 1982, all dilutions were set in duplicate. Plates with acceptable counts were averaged to give the colonies per 100 ml (col/100 ml) reported in this table. If no plates were within the range, the plate closest to the range was reported.

FECAL COLIFORM (COL/100 ML)

The influent fecal coliform density was determined for each sample. The USEPA direct membrane filter procedure was followed. Four dilutions were routinely set in duplicate (starting in May 1982). All plates were set within two hours after sampling. Coliform densities from plates with acceptable counts were averaged to give the colonies per 100 ml (col/100 ml) reported in this table. If no plate was within that range the plate closest to the range was reported.

Table 2A. Influent (Secondary) to UV Units-UV Absorbance

The absorbance coefficients of the influent samples are presented in Table 2A. The influent samples are all of secondary effluent from the Port Richmond Plant. Each parameter is discussed below under the heading as it appears on the table. If an absorbance was not measured, a series of asterisks (*) appear in that column.

DIRECT UV TOTAL (CM-1)

The direct UV absorbance of the unfiltered influent sample was measured routinely for the entire length of the experimental program. The UV absorbance at 253.7 nm was measured with a Perkin Elmer 552A UV-Visible spectrophotometer using a 1 cm quartz cell. Absorbance units per centimeter (a.u./cm) is read directly. The absorbance coefficient, as reported, is in base e and is equal to 2.3 times the instrument readout.

DIRECT UV FILTER (CM-1)

The direct UV absorbance of the filtered influent sample was measured following the same schedule and procedure as the direct UV absorbance on the unfiltered sample.

SPHERE UV TOTAL (CM-1)

The sphere UV absorbance of the unfiltered influent sample followed the same schedule as the direct UV absorbance. An integrating sphere (#B010-3751) was inserted into the spectrophotometer for measurement (and correction of absorbance) of the scattered light. Thus the absorbance reported with this procedure is an estimate of "true" absorbance of the liquid. The procedure for measuring and recording the "spherical" UV absorbance is the same as that discussed for the direct UV absorbance.

SPHERE UV FILTER (CM-1)

The sphere UV absorbance of the filtered influent sample was measured following the same method discussed for the sphere UV total sample.

Table 2B. Influent (Secondary) to UV Units-Water Quality

Table 2B presents parameters routinely measured on the influent to the UV units. Influent in this case is the secondary effluent from the Port Richmond Plant. Each parameter is discussed below under the heading as it appears on the table. If an analysis was not performed on a sample, a series of asterisks (*) appear in that column.

COD TOTAL (mg/1)

The chemical oxygen demand (COD) of all unfiltered influent samples was routinely determined until April 25, 1983. From that time on, the frequency of the COD analyses was reduced to once per sampling day.

The dichromate reflux procedure in Standard Methods was followed for all COD analyses.

COD FILTER (mg/1)

The frequency and procedures followed for the COD analyses on the filtered influent samples was the same as for the COD total samples.

TOC TOTAL (mg/1)

The schedule followed for the unfiltered influent total organic carbon (TOC) analyses was the same as that followed for the COD analyses.

All TOC measurements were done with an Oceanography International Model 0524B-HR Total Organic Carbon Analyzer.

TOC FILTER (mg/l)

The schedule and procedures followed for the filtered influent TOC analyses was the same as that followed for the unfiltered TOC analyses.

TKN TOTAL (mg/l)

The total kjeldahl nitrogen (TKN) of the unfiltered influent sample was measured on all samples taken one day a week. TKN analyses were discontinued after March 7, 1983. The TKN analyses were performed by an automated phenate method with a Technicon BD-40 Block Digester and Technicon II Autoanalyzer.

TKN FILTER (mg/l)

The schedule and the method of analysis followed for the filtered influent TKN samples was the same as for the unfiltered samples.

NH_3-N (mg/l)

Ammonia-nitrogen (NH_3-N) analyses followed the same schedule as TKN. Analyses on filtered influent samples were done following an automated phenate method using a Technicon II Autoanalyzer.

NO_2-N (mg/l)

Nitrite-nitrogen (NO_2-N) analyses were done on filtered influent samples using an automated diazotization method with a Technicon I autoanalyzer. The analytical schedule followed was the same as for the TKN analyses.

NO_3-N (mg/l)

Nitrate-nitrogen (NO_3-N) analyses were done on filtered influent samples with a Technicon I Autoanalyzer using an automated brucine method. The frequency of analyses was the same as that for TKN.

Table 3. Unit 1 (Widely Spaced Quartz System) Operating Conditions

Table 3 presents the daily operating conditions of Unit 1, which was the widely spaced quartz system (lamp spacing 5.0 cm). The parameters recorded each sampling day are discussed below under the heading as it appears on the table.

WIPER RATE (CPH)

The wiper stroke rate in cycles per hour (CPH) was recorded each sampling day. One cycle consisted of the wiper moving from one side of the unit to the other. The next cycle would bring the wiper back to its original position. If the unit was down or the wiper off for a wiper study, the wiper rate is indicated by asterisks (*).

LAMP TEMP (C)

The temperature of one lamp in the unit was recorded in degrees Celsius (°C) once each sampling day. If no reading was taken because either the unit or the probe was down, asterisks (*) appear in the column.

LAMPS ON

The number of UV lamps operating at the time of the daily unit monitoring was recorded. This number may not correspond to the number of lamps on during sampling. The number of lamps on for each sampling is recorded in Table 4. An entry of zero (0) for the number of lamps on indicates the unit was not sampled that day.

VOLTAGE (%)

The voltage setting on the variac was recorded each sampling day. An entry of zero (0) indicates the unit not sampled.

I METER A (%), I METER B (%), I METER C (%)

The readout of the internal intensity monitors in banks A, B and C were recorded each sampling day the monitors were operational. The monitors failed in June 1982 and were not repaired. If the unit was down or the monitors not operational a series of asterisks (*) are recorded on the table.

IL 570 INF (W/CM2)

An intensity measurement was taken with the detector positioned halfway across the influent plane of the UV unit and resting on the wiper bar. The intensity measurements are given in watts per square centimeter (w/cm^2). If no measurement of intensity was made, a value of 0.00E 00 was recorded for that day. All intensity measurements were made with an IL 570 Radiometer which used an SEA-240 detector with a W quartz wide eye diffuser and an NBS 254 filter.

It should be noted that these measurements are relative values and are not measures of actual UV intensity.

IL 570 EFF (W/CM2)

Three intensity measurements were made across the exit plane of the UV unit 25.4 cm apart. The three intensities were averaged and the average recorded in this table. The intensity measurements are given in watts per square centimeter (w/cm^2). If no intensity measurements were made, a value of 0.00E 00 was recorded for that day. Measurements were made using the same detector described above.

It should be noted that these measurements are relative values and are not measures of accurate measures UV intensity within the system.

Table 4. Unit 1 (Widely Spaced Quartz System) Effluent-Secondary

Table 4 presents the operating conditions and performance for each effluent sampling of Unit 1. Each parameter is discussed below under the heading as it appears on the table. Data represent only those samplings when the Unit was receiving secondary effluent.

All effluent samples were grabs taken from the effluent tank of the unit using a Wheaton Remote sampler.

FLOW (L/MIN)

The flow through the unit was monitored by a 25.4 cm Palmer Bowlus flume in conjunction with an ISCO Model 1700 flow meter. The effluent height in the flume was recorded at each sampling and converted to liters per minute (l/min) using a calibration curve. If the unit was not sampled, a series of asterisks (*) appear in the column.

VOLTAGE (%)

The power setting on the variac was recorded at each sampling. If the unit was not sampled, a zero (0) appears in this column.

BANKS ON

The number of lamp banks on was recorded at each sampling. If the unit was not sampled, a zero (0) appears in this column.

LAMPS ON

The number of lamps on at the time of sampling is recorded in this column. A zero (0) in this column indicates that the unit was not sampled.

TOTAL COLI (COL/100)

The effluent total coliform density was determined whenever the unit was sampled. The USEPA single step membrane filter (MF) procedure was followed. All plates were set within two hours after sampling. Four dilutions were routinely set in duplicate (starting in May 1982). Plates with acceptable counts were averaged to give the colonies per 100 ml (col/100) reported in this table. If no plate was within the range the plate closest to the range was reported. If total coliforms were not enumerated, a series of asterisks (*) appear in this column.

FECAL COLI (COL/100)

The effluent fecal coliform density was determined whenever the unit was sampled. The USEPA direct membrane filter (MF) procedure was followed. All plates were set within two hours after sampling. Four dilutions were routinely set in duplicate (starting in May 1982). Plates with acceptable counts were averaged to give the colonies per 100 ml (col/100) reported in this table. If no plate was within the range, the plate closest to the ranges was reported. If fecal coliforms were not enumerated, a series of asterisks (*) appear in this column.

Table 5. Unit 2 (Closely Spaced Quartz System) Operating Conditions

Table 5 presents the daily operating conditions for Unit 2, which was the closely spaced quartz system (lamp spacing 1.25 cm). The parameters recorded each sampling day are discussed below under the heading as it appears on the table.

WIPER RATE (CPH)

The wiper stroke rate in cycles per hour (CPH) was recorded each samplng day. One cycle consisted of the wiper moving from one side of the unit to the other. The next wiper cycle would bring the wiper back to its original position. If the unit was down, or the wiper off for a wiper study, the wiper rate is indicated by asterisks (*).

LAMP TEMP (C)

The temperature of one lamp in the unit was recorded in degrees Celsius (°C) several days during the experimental program. (The temperature probe was left in Unit 1 for most of the study). A series of asterisks (*) in this column indicate no temperature was recorded.

LAMPS ON

The number of UV lamps operating at the time of the daily monitoring was recorded. This number may not correspond to the number of lamps on during sampling. The number of lamps on for each sampling is recorded on Table 6. An entry of zero (0) for the number of lamps on indicates the unit was not sampled that day.

VOLTAGE (%)

The voltage setting on the variac was recorded each sampling day. An entry of zero (0) indicates the unit was not sampled.

I METER A (%), I METER B (%), I METER C (%)

The readout of the internal intensity monitors in banks A, B and C were recorded each sampling day the monitors were operational. The monitors failed in March 1982 and were not repaired. If the unit was down or the monitors not operational, a series of asterisks (*) are recorded on the table.

IL 570 INF (W/CM2)

An intensity measurement was taken with the detector positioned halfway across the influent plane of the UV unit and resting on the wiper bar. The intensity measurements are given in watts per square centimeter (w/cm^2). If no measurement of intensity was made a value of 0.00E 00 was recorded for that day. All intensity measurements were made with an IL 570 Radiometer which used an SEA-240 detector with a W quartz wide eye diffuser and an NBS254 filter.

It should be noted that these measurements are relative values and are not accurate measures of actual UV intensity within the unit.

IL 570 EFF (W/CM2)

Three intensity measurements were made across the exit plane of the UV unit 25.4 cm apart. The three intensities were averaged and the average recorded on this table. The intensity measurements are given in watts per square centimeter (w/cm^2). If no intensity measurements were made 0.00E 00 was recorded for that day. Measurements were made using the same detector described above.

It should be noted that these measurements are relative values and are not accurate measures of actual UV intensity within the unit.

Table 6. Unit 2 (Closely Spaced Quartz System) Effluent-Secondary

Table 6 presents the operating conditions and performance for each effluent sampling of Unit 2. Each parameter is discussed below under the heading as it appears in the table. Data represent only those samplings when the Unit was receiving secondary effluent.

All effluent samples were grabs taken from the effluent tank of the unit using a Wheaton Remote sampler.

FLOW (L/MIN)

The flow through the unit was monitored by a 25.4 cm Palmer Bowlus flume in conjunction with an ISCO Model 1700 flow meter. The effluent height in the flume was recorded at each sampling and converted to liters per minute (l/min) using a calibration curve. If the unit was not sampled, a series of asterisks (*) appear in the column.

VOLTAGE (%)

The power setting on the variac was recorded at each sampling. If the unit was not sampled, a zero (0) appears in this column.

BANKS ON

The number of lamp banks on was recorded at each sampling. If the unit was not sampled, a zero (0) appears in this column.

LAMPS ON

The number of lamps on at the time of sampling is recorded in this column. A zero (0) in this column indicates that the unit was not sampled.

TOTAL COLI (COL/100)

The effluent total coliform density was determined whenever the unit was sampled. The USEPA single step membrane filter (MF) procedure was followed. All plates were set within two hours after sampling. Four dilutions were routinely set in duplicate (starting in May 1982). Plates with acceptable counts were averaged to give the colonies per 100 ml (col/100 ml) reported in this table. If no plate was within the range, the plate closest to the range was reported. If total coliform were not enumerated, a series of asterisks (*) appear in this column.

FECAL COLI (COL/100)

The effluent fecal coliform density was determined whenever the unit was sampled. The USEPA direct membrane filter (MF) procedure was followed. All plates were set within two hours after sampling. Four dilutions were routinely set in duplicate (starting in May 1982). Plates with acceptable counts were averaged to give the colonies per 100 ml (col/100 ml) reported in this table. If no plate was within the range, the plate closest to the range was reported. If fecal coliforms were not enumerated, a series of asterisks (*) appear in this column.

Table 7. Unit 3 (Teflon System) Operating Conditions

Table 7 presents the daily operating conditions for the teflon unit. The parameters recorded each sampling day are discussed below under the heading as it appears on the table.

LAMP TEMP (C)

The lamp temperature in degrees Celsius (^{o}C) was recorded on any day the unit was sampled and the temperature probe operational. A series of asterisks (*) in this column indicates that the temperature was not recorded for one of the above reasons.

LAMPS ON

The number of lamps on for each sampling was recorded. If the unit was not sampled, a zero (0) appears in this column.

I METER A, I METER B, I METER C, I METER D

The readout from the four internal intensity probes (A, B, C and D) were recorded each day the unit was sampled and the meters operational. These readings are in percent and are relative to tap water (100%). Lamp performance in addition to water quality variations influence the readings of these meters.

Table 8. Unit 3 (Teflon System) Effluent-Secondary

Table 8 presents the operating conditions and performance for each effluent sampling of Unit 3. Each parameter is discussed below under the heading as it appears on the table. Data represent only those samplings when the unit was receiving secondray effluent.

Effluent grab samples from the teflon unit were taken from the effluent flume when all channels were in operation. When only one channel was in use, samples were taken at the overflow weir for that particular compartment.

FLOW (L/MIN)

The flow through the unit was monitored by a 25.4 cm Palmer-Bowlus flume. The effluent height in the flume was recorded at each sampling and converted to liters per minute (l/min) using a calibration curve. If the unit was not sampled, a series of asterisks (*) appear in the column.

BANKS ON

The number of lamp banks on was recorded at each sampling. The teflon unit had 36 indicators of lamp operation mounted on the outside of the unit. Each indicator represents one set of two lamps (one ballast). If the entire unit was in use, a maximum of 36 banks were operational. With only one channel in operation, a maximum of 12 banks were operational.

If the unit was not sampled, a zero (0) appears in this column.

LAMPS ON

The number of lamps on was recorded at each sampling. The number of lamps on assumes that each indicator represented two lamps in operation. If the unit was not sampled, a zero (0) appears in this column.

TOTAL COLI COL/100

The effluent total coliform density was routinely determined whenever the unit was sampled. The USEPA single step membrane filter (MF) procedure was followed. All plates were set within two hours after sampling. Four dilutions were routinely set in duplicate. Plates with acceptable counts were averaged to give colonies per 100 ml (col/100 ml), as reported in this table. If no plate was within the range, the plate closest to the ranges was reported. If total coliform were not enumerated, a series of asterisks (*) appear in this column.

FECAL COLI COL/100

The effluent fecal coliform density was routinely determined whenever the unit was sampled. The USEPA direct membrane filter (MF) procedure was followed. All plates were within two hours after sampling. Four dilutions were routinely set in duplicate. Plates with acceptable counts were averaged to give the colonies per 100 ml (col/100 ml) reported in this table. If no plate was within the range, the plate closest to the range was reported. If fecal coliforms were not enumerated, a series of asterisks (*) appear in this column.

Table 9. Influent (Primary) to UV Units-Water Quality and Bacteriology

Table 9 presents parameters routinely measured on a CSO quality influent to the UV units. The wastewater was primary effluent by-passed around the secondary treatment system. If an analysis was not performed on a sample, a series of asterisks (*) appear in that column.

All influent samples were grabs taken from the influent tank of one of the UV units. Note that all primary effluent samples were blended at high speed for 20 to 30 seconds before any plates were set for total and fecal coliform enumeration.

Refer to Table 2 for an explanation of headings.

Table 9A. Influent (Primary) to UV Units-Water Quality

Table 9A presents the absorbance coefficient for the influent to the UV units. The influent in this case was primary effluent from the Port Richmond Plant. If an absorbance was not measured, a series of asterisks (*) appear in that column.

Refer to Table 2A for an explanation of headings.

Table 9B. Influent (Primary) to UV Units-Water Quality

Table 9B presents parameters routinely measured when Port Richmond primary effluent was discharged to the UV units. If an analysis was not performed on a sample, a series of asterisks (*) appear in that column.

Refer to Table 2B for an explanation of headings.

Table 10. Unit 1 (Widely Spaced Quartz System) Effluent-Primary

Table 10 presents the operating conditions and performance of Unit 1 at the time of each effluent sampling. Data represent samplings when the unit was receiving primary effluent.

All effluent samples were grabs taken from the effluent tank of the unit using a Wheaton Remote sampler. The efluent samples were blended for 20 to 30 seconds at high speed before any total or fecal coliform plates were set.

Refer to Table 4 for an explanation of headings.

Table 11. Unit 2 (Closely Spaced Quartz System) Effluent-Primary

Table 11 presents the operating conditions and performance for Unit 2 at the time of each effluent sampling. Data represent samplings with the unit was receiving primary effluent.

All effluent samples were grabs taken from the effluent tank of the unit using a Wheaton Remote sampler. The effluent samples were blended for 20 to 30 seconds at high speed before total or fecal coliform plates were set.

Refer to Table 6 for an explanation of headings.

CODE DAY NO	DATE	TIME	INF TEMP (C)	AIR TEMP (C)	POWER (KWHR)	POWER TIME
002	12/02/81	1430	*****	*****	00805	1430
003	12/03/81	1300	*****	*****	00932	1300
007	12/07/81	1458	*****	*****	01458	0930
014	12/14/81	1130	*****	0.0	01921	1130
015	12/15/81	1000	*****	1.6	02038	1000
016	12/16/81	1000	*****	-1.1	02160	1000
017	12/17/81	0800	*****	-2.7	02275	0800
021	12/21/81	0930	*****	-3.8	03765	0930
023	12/23/81	1000	*****	1.6	03937	1000
028	12/28/81	0800	*****	1.6	03551	0800
029	12/29/81	0830	*****	1.6	03680	0830
035	01/04/82	0930	11.0	4.4	04433	0930
037	01/06/82	0700	12.0	3.3	04607	1320
038	01/07/82	0630	12.0	4.4	04700	0630
041	01/11/82	1315	11.0	-12.2	05214	1315
042	01/12/82	0930	12.0	-14.4	05323	0930
051	01/20/82	0930	12.0	-3.8	06223	0930
058	01/27/82	0900	*****	-6.6	06675	0900
059	01/28/82	1000	11.5	-3.8	06737	1000
066	02/04/82	0930	8.5	4.4	07084	0930
071	02/09/82	1100	11.0	1.6	07704	1100
072	02/10/82	0900	11.0	-3.8	07821	0900
073	02/11/82	1030	11.0	-3.8	07948	1030
078	02/16/82	1100	12.0	4.4	08478	1100
079	02/17/82	0930	12.0	0.0	08589	0930
086	02/24/82	0930	12.0	0.0	08722	0930
087	02/25/82	0930	11.5	-2.7	08733	0945
091	03/01/82	1330	11.5	0.0	08774	1330
092	03/02/82	1000	12.0	2.7	08822	1000
093	03/03/82	1015	12.5	-2.2	08884	1030
094	03/04/82	1015	12.5	-2.2	08906	1015
098	03/08/82	1415	12.5	-1.1	09153	1415
099	03/09/82	0930	11.5	-1.1	09212	1430
100	03/10/82	1100	11.5	0.5	09304	1100
105	03/15/82	1330	12.0	4.4	10057	1315
106	03/16/82	1130	12.5	4.4	10225	1200
107	03/17/82	1315	12.0	4.4	10368	1315
149	04/28/82	1115	14.5	10.0	17053	1115
150	04/29/82	1100	14.5	12.7		
154	05/03/82	1330	16.0	21.1	17133	1330
155	05/04/82	1130	16.0	18.3	17406	1145
156	05/05/82	1400	16.5	21.1		
157	05/06/82	1430	16.5	21.1	17861	1430
161	05/10/82	1400	16.5	23.9	18460	1400
162	05/11/82		16.5	18.3		
168	05/17/82		*****	*****		
169	05/18/82	1030	18.0	21.1		
171	05/20/82	1015	19.5	21.1	19154	1015
176	05/25/82	1245	*****	23.9	19442	1245

Table 1. Daily Operating Conditions

CODE DAY NO	DATE	TIME	INF TEMP (C)	AIR TEMP (C)	POWER (KWHR)	POWER TIME
177	05/26/82	1000	*****	*****	20703	1000
183	06/01/82	1000	*****	*****	21351	1000
196	06/14/82		*****	*****	21755	1445
197	06/15/82		*****	*****	22050	1700
198	06/16/82		*****	*****	22223	1515
203	06/21/82	1100	19.5	21.1	22512	1100
204	06/22/82	1000	19.5	21.1	22575	1000
205	06/23/82	1000	19.5	21.1	22880	1015
210	06/28/82	0930	20.0	23.9	23240	0900
211	06/29/82	0800	20.5	23.9	23537	0800
212	06/30/82	0800	20.5	23.9	23838	0830
218	07/06/82	0830	21.0	23.9	25648	0830
219	07/07/82		21.0	26.6		
225	07/13/82	0815	21.5	29.4	26326	0830
226	07/14/82	0930	21.5	32.2	26504	0930
231	07/19/82	0900	23.0	32.2	27372	0900
239	07/27/82	0830	23.0	29.4	29405	0915
240	07/28/82	0830	23.0	26.6	29593	0715
241	07/29/82	0800	23.0	23.9	29803	0730
245	08/02/82	0830	22.5	23.9	30705	0715
246	08/03/82	0800	22.5	23.9	31088	1515
247	08/04/82	0800	23.0	29.4	31187	0800
252	08/09/82	0830	23.0	29.4	32573	1515
253	08/10/82	0730	23.0	25.5	32765	0745
254	08/11/82	0900	23.5	21.1	32840	0900
260	08/17/82	1015	23.5	26.6	33009	1030
266	08/23/82	0850	23.0	23.9		
267	08/24/82	0800	23.0	26.6		
268	08/25/82	0750	23.5	23.9		
274	08/31/82		*****	21.1		
275	09/01/82	1530	*****	*****	33383	1530
281	09/07/82	0930	23.0	21.1		
282	09/08/82	1130	22.5	21.1		
296	09/22/82	1200	*****	15.5		
308	10/04/82	1200	22.0	23.9	33715	1200
309	10/05/82	1000	22.0	23.9	34054	1000
310	10/06/82	1015	22.5	21.1	34230	1015
315	10/12/82	1430	22.0	18.3	35607	1430
316	10/13/82	1100	22.0	18.3	35735	1100
321	10/18/82	1200	21.0	12.7	36346	1200
322	10/19/82	1000	21.0	12.7	36470	1000
329	10/25/82	1610	21.0	10.0	36608	1610
330	10/26/82	1215	16.5	12.7	36782	1215
331	10/27/82	1130	16.0	12.7	37982	1130
337	11/02/82	1000	20.0	23.9	38235	1030
338	11/03/82	1000	20.0	15.5	38369	1015
343	11/08/82	1300	19.5	18.3	39432	1300
345	11/10/82	1000	19.5	10.0	39615	1000
350	11/15/82	1130	18.0	7.2	40675	1130

Table 1. (Continued)

CODE DAY NO	DATE	TIME	INF TEMP (C)	AIR TEMP (C)	POWER (KWHR)	POWER TIME
351	11/16/82	1030	17.5	7.2	40798	1030
352	11/17/82	1130	18.5	10.0	40927	1130
353	11/18/82	1145	19.5	7.2	41051	1145
357	11/22/82	1430	19.0	15.5	41563	1430
358	11/23/82	1100	19.5	15.5	41676	1200
364	11/29/82	1100	15.0	10.0	42413	0930
365	11/30/82	1300	17.0	12.7	42646	1300
366	12/01/82	1145	17.5	10.0	42842	1145
367	12/02/82	1200	*****	12.7	43051	1200
371	12/06/82	1200	19.0	18.3	43867	1200
372	12/07/82	1130	19.0	10.0	43965	1130
373	12/08/82	1130	18.0	4.4	44073	1130
378	12/13/82	1200	16.0	-3.8	44593	1200
379	12/14/82	1130	17.0	-3.8	44603	1130
380	12/15/82	1430	17.0	7.2	44903	1430
381	12/16/82	1200	16.0	7.2	45102	1200
385	12/20/82	1130	*****	-1.1	46908	1130
386	12/21/82	1115	*****	3.3	46131	1115
399	01/03/83	1230	16.7	1.6	47054	1230
400	01/04/83	1030	16.7	-3.8	47260	1030
401	01/05/83	1145	15.6	-1.1	47487	1145
402	01/06/83	1030	13.9	1.6	47706	1030
406	01/10/83	1330	15.6	1.6	48592	1330
407	01/11/83	1200	13.9	10.0	48796	1200
408	01/12/83	1045	15.0	-1.1	49003	1045
409	01/13/83	1145	14.0	-5.5	49223	1145
413	01/17/83	1300	12.5	-6.6	50113	1300
414	01/18/83	1030	12.5	-9.4	50310	1030
415	01/19/83	1200	13.0	-9.4	50541	1200
416	01/20/83	1200	12.0	-12.2	50766	1200
420	01/24/83	1245	10.5	-1.1	51589	1245
421	01/25/83	1100	12.0	4.4	51780	1100
422	01/26/83	1200	12.0	-1.1	52018	1215
423	01/27/83	1200	13.0	-1.1	52238	1200
427	01/31/83	1130	12.0	4.4	53113	1130
428	02/01/83		12.0	4.4	53332	1215
429	02/02/83		13.0	5.5	53548	
430	02/03/83		12.0	10.0	53773	1200
441	02/14/83	1230	12.0	-1.1	56958	1230
444	02/17/83	1130	10.5	4.4	56476	1130
455	02/28/83	1100	12.5	4.4	58622	1100
462	03/07/83	1100	11.5	7.2	59069	1130
463	03/08/83	1100	11.5	4.4	59182	1115
464	03/09/83	1100	10.5	4.4	59294	1100
469	03/14/83	1145	12.5	10.0	60149	1345
470	03/15/83	0900	13.0	12.7	60314	0900
471	03/16/83	0900	13.0	7.2	60438	0900
472	03/17/83	1100	13.0	4.4	60558	1100
476	03/21/83	1130	12.5	4.4	61433	1130

Table 1. (Continued)

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*   CODE    *  *   DATE   *  *TIME*  *INF TEMP*  *AIR TEMP*  * POWER *  * POWER *
* DAY NO    *  *          *  *    *  *  (C)   *  *  (C)   *  * (KWHR)*  *  TIME  *

    477          03/22/83     1130       12.0          4.4       61653       1130
    478          03/23/83     1415      *****          1.6       61807       1415
    479          03/24/83     1045       11.5          1.6       62092       1045
    483          03/28/83     1030       11.0         10.0       62523       1030
    484          03/28/83     0900       12.0          7.2       62646       0900
    497          04/11/83     1300       13.0         10.0       62714       1300
    498          04/12/83     1000       13.0          8.8       62830       1000
    499          04/13/83     1115       13.0          8.8       63037       1130
    500          04/14/83               *****          7.2
    504          04/18/83     1200       12.5          4.4       64101       1200
    505          04/19/83     1030       11.0          4.4       64227       1030
    506          04/20/83     1000       11.0          4.4       64427       1000
    507          04/21/83     1145      *****         10.0       64640       1145
    511          04/25/83     1000      *****        *****
    512          04/26/83     1000      *****        *****
    513          04/27/83     0930       13.5         12.7       65394       1530
    514          04/28/83     0900       14.0         23.9       65553       0900
    520          05/04/83     1115       10.0         18.3       66348       1115
    521          05/05/83     1130       16.0         12.7       66483       1145
    574          06/27/83     0900       21.0         26.6
    575          06/28/83     0900      *****         26.6
    576          06/29/83     0830       20.5         23.9
    577          06/30/83     1100       21.0         26.6
    589          07/12/83     1000       22.0         29.4       67428       1000
    590          07/13/83     1030       22.5         26.6       67507       1030
    591          07/13/83     1030       22.5         29.4       67592       1030
    595          07/18/83     1000       22.5         26.6       67614       1000
    596          07/19/83     1015       23.5         29.4       67742       1015
    597          07/20/83     1045       24.0         29.4       67874       1045
    602          07/25/83     1030       23.0         26.6       68507       1030
    603          07/26/83     0915       23.0         23.9       68633       0915
    604          07/27/83     0845       23.0         21.1       68761       0845
    605          07/28/83     1030       23.0         23.9       68909       1200
    609          08/01/83     0915       23.5         23.9       69412       0915
    610          08/02/83     0905       23.5         21.1       69547       0905
    611          08/03/83     0910       23.5         23.9       69667       0910
    612          08/04/83     0915       23.5         26.6       69896       0915
    616          08/08/83     0930       23.0         26.6       70314       0930
    617          08/09/83     0930       23.5         23.9       70472       0930
    618          08/10/83     0930       23.0         21.1       70545       0930
    619          08/11/83     0910       23.0         21.1       70612       0910
    630          08/22/83     0900       22.0         21.1
    631          08/23/83     1000       22.0         26.6
    632          08/24/83                 0.0         26.6
    633          08/25/83     1200       23.0         26.6       71474       1600
    637          08/29/83     1030       22.5         26.6       72973       1030
    638          08/30/83     1115       22.5         23.9       72195       1115
    639          08/31/83     1130       22.5         21.1
    640          09/01/83     1100       22.5         23.9       72227       1645
    645          09/06/83     1130       24.0         32.2       72589       1115
    646          09/07/83     1030       24.0         32.2       72714       1030
    647          09/08/83     1100       24.0         29.4       72842       1030
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CODE	DATE	TIME	TURBIDITY (NTU)	SS (MG/L)	PH	TOTAL COLIFORM (COL/100ML)	FECAL COLIFORM (COL/100ML)
U02-001	12/02/81	0930	3.1	4.0	7.1	20000000.	***********
U02-002	12/02/81	1045	3.6	3.0	7.0	22000000.	***********
U02-003	12/02/81	1200	5.0	3.0	7.6	9000000.	***********
U02-004	12/02/81	1430	3.9	7.0	7.6	17000000.	***********
U03-005	12/03/81	0830	4.3	12.0	6.7	76000000.	***********
U03-006	12/03/81	1045	4.3	9.0	6.7	90000000.	***********
U03-007	12/03/81	1130	4.3	14.0	6.8	56000000.	***********
U03-008	12/03/81	1300	3.9	11.0	6.7	85000000.	***********
U07-009	12/07/81	0930	2.8	8.0	7.3	3900000.	***********
U07-010	12/07/81	1350	2.7	6.0	7.2	2600000.	***********
U07-011	12/07/81		2.2	7.0	7.1	3600000.	***********
U14-012	12/14/81	0800	4.0	25.0	6.7	1400000.	***********
U14-013	12/14/81	1130	5.0	26.0	6.7	930000.	110000.
U14-014	12/14/81	1415	5.4	34.0	6.9	1000000.	170000.
U15-015	12/15/81	1030	4.2	19.0	6.2	660000.	90000.
U15-016	12/15/81	1200	7.3	26.0	6.3	1700000.	70000.
U15-017	12/15/81	1330	5.4	23.0	6.4	670000.	60000.
U16-018	12/16/81	1115	3.8	17.0	6.4	390000.	70000.
U16-019	12/16/81	1230	4.7	13.0	6.4	360000.	70000.
U17-020	12/17/81	0830	3.8	16.0	7.2	420000.	30000.
U17-021	12/17/81	1115	4.3	14.0	6.9	330000.	60000.
U17-022	12/17/81	1415	5.4	22.0	7.4	320000.	40000.
U21-023	12/21/81	0930	22.0	54.0	7.2	970000.	70000.
U21-024	12/21/81	1130	19.0	36.0	6.6	740000.	270000.
U21-025	12/21/81	1345	18.0	47.0	6.7	680000.	1300000.
U23-026	12/23/81	1000	15.0	70.0	6.8	970000.	217000.
U23-027	12/23/81	1130	10.0	63.0	6.4	1100000.	270000.
U23-028	12/23/81	1330	9.8	59.0	6.8	1600000.	170000.
U28-029	12/28/81	0830	3.0	22.0	6.1	1360000.	200000.
U28-030	12/28/81	1000	2.8	13.0	6.4	1000000.	260000.
U28-031	12/28/81	1230	2.5	14.0	7.0	1170000.	420000.
U29-032	12/29/81	0900	2.1	16.0	7.1	1100000.	***********
U29-033	12/29/81	1130	3.4	21.0	7.1	1100000.	290000.
U29-034	12/29/81	1330	3.2	17.0	7.1	1600000.	410000.
U35-035	01/04/82	1000	*****	14.0	7.2	600000.	140000.
U35-036	01/04/82		*****	7.0	7.1	745000.	173000.
U35-037	01/04/82		*****	14.0	7.1	660000.	210000.
U35-038	01/04/82		*****	8.0	6.8	730000.	150000.
U37-039	01/06/82	0700	2.6	9.0	7.4	1470000.	320000.
U37-040	01/06/82	0930	2.4	7.0	7.4	693000.	220000.
U37-041	01/06/82	1200	2.5	7.0	7.3	490000.	200000.
U38-042	01/07/82	0700	2.4	6.0	7.4	610000.	360000.
U38-043	01/07/82	1200	4.6	15.0	7.3	1250000.	450000.
U41-044	01/11/82	1330	2.6	9.0	7.2	2220000.	760000.
U42-045	01/12/82	0945	4.3	22.0	7.1	2130000.	580000.
U42-046	01/12/82	1115	4.4	20.0	7.0	2240000.	745000.
U42-047	01/12/82	1400	.6	23.0	6.9	2300000.	650000.
U51-048	01/20/82	1015	4.2	15.0	6.9	1030000.	340000.

Table 2. Influent (Secondary) to UV Units - Water Quality and Bacteriology

CODE	DATE	TIME	TURBIDITY (NTU)	SS (MG/L)	PH	TOTAL COLIFORM (COL/100ML)	FECAL COLIFORM (COL/100ML)
051-049	01/20/82	1145	4.7	13.0	6.8	1000000.	500000.
051-050	01/20/82	1315	4.2	12.0	6.6	1230000.	430000.
058-051	01/27/82	0945	3.1	12.0	6.8	1230000.	520000.
058-052	01/27/82	1145	2.4	10.0	6.7	1770000.	614000.
058-053	01/27/82	1315	3.6	15.0	6.7	1630000.	257000.
059-054	01/28/82	1000	4.0	16.0	6.7	2280000.	750000.
059-055	01/28/82	1145	5.1	21.0	7.1	2370000.	1230000.
059-056	01/28/82	1330	6.5	26.0	7.2	2540000.	1400000.
066-057	02/04/82	1000	1.1	8.0	7.0	682000.	200000.
066-058	02/04/82	1330	1.2	13.0	7.0	1230000.	310000.
071-059	02/09/82	1115	5.9	26.0	6.8	610000.	227000.
071-060	02/09/82	1400	4.6	21.0	6.9	900000.	285000.
072-061	02/10/82	0930	3.6	22.0	6.7	2190000.	580000.
072-062	02/10/82	1130	5.3	28.0	6.6	1900000.	755000.
072-063	02/10/82	1430	34.0	65.0	6.5	6900000.	1170000.
073-064	02/11/82	1030	8.4	20.0	6.7	4500000.	1990000.
073-065	02/11/82	1230	8.2	34.0	6.5	4400000.	2250000.
073-066	02/11/82	1430	7.5	24.0	6.7	7000000.	1930000.
078-067	02/16/82	1100	3.9	17.0	7.3	4500000.	267000.
078-068	02/16/82	1330	4.5	26.0	7.1	6700000.	967000.
079-069	02/17/82	1000	29.0	48.0	7.0	12000000.	2100000.
079-070	02/17/82	1145	28.5	50.0	6.9	9670000.	4000000.
079-071	02/17/82	1400	29.0	45.0	****	15000000.	2100000.
086-072	02/24/82	1000	5.6	35.0	****	10700000.	1850000.
086-073	02/24/82		6.0	34.0	****	12300000.	2400000.
087-074	02/25/82	1000	5.2	29.0	7.4	8300000.	2310000.
087-075	02/25/82	1400	5.3	20.0	7.1	18300000.	2130000.
091-076	03/01/82	1030	5.2	25.5	7.1	***********	160000.
091-077	03/01/82	1230	4.7	22.0	7.1	***********	183000.
091-078	03/01/82	1400	5.0	21.0	7.0	***********	220000.
092-079	03/02/82	1000	4.5	26.0	7.3	***********	310000.
092-080	03/02/82	1200	5.3	23.0	7.3	***********	590000.
092-081	03/02/82	1400	5.0	22.0	7.2	***********	680000.
093-082	03/03/82	1030	5.7	21.0	7.5	1433300.	870000.
093-083	03/03/82	1230	5.6	22.0	5.6	***********	620000.
093-084	03/03/82		5.7	22.0	6.6	***********	620000.
094-085	03/04/82	1030	5.9	31.0	7.4	***********	833000.
094-086	03/04/82	1230	6.1	28.0	7.2	***********	510000.
094-087	03/04/82	1400	6.1	26.0	7.3	***********	800000.
098-088	03/08/82	1115	6.2	36.0	6.4	706700.	335000.
098-089	03/08/82	1230	4.9	21.0	7.1	730000.	210000.
098-090	03/08/82	1430	5.2	19.0	7.3	700000.	290000.
099-091	03/09/82	1000	8.3	42.0	6.8	1750000.	340000.
099-092	03/09/82	1200	8.1	38.0	7.2	1780000.	570000.
099-093	03/09/82	1430	8.0	40.0	6.6	2800000.	1030000.
100-094	03/10/82	1115	6.2	25.0	7.3	2150000.	770000.
100-095	03/10/82	1400	8.0	25.0	7.0	1770000.	800000.
105-096	03/15/82	0915	4.2	17.0	****	220000.	70000.

Table 2. (Continued)

CODE	DATE	TIME	TURBIDITY (NTU)	SS (MG/L)	PH	TOTAL COLIFORM (COL/100ML)	FECAL COLIFORM (COL/100ML)
105-097	03/15/82		4.6	11.0	****	200000.	120000.
106-098	03/16/82	0930	5.4	11.0	****	330000.	70000.
106-099	03/16/82	1200	5.0	22.0	****	600000.	300000.
106-100	03/16/82	1400	5.1	20.0	****	370000.	190000.
107-101	03/17/82	1130	3.7	12.0	7.0	170000.	58000.
107-102	03/17/82	1430	3.5	10.0	6.9	340000.	130000.
149-103	04/28/82	1015	8.1	46.0	7.0	440000.	2700000.
149-104	04/28/82	1130	13.0	62.0	7.0	1783300.	200000.
149-105	04/28/82	1330	16.0	67.0	7.0	2150000.	1166700.
150-106	04/29/82	1015	4.5	52.0	7.1	616600.	1133300.
154-107	05/03/82	1200	15.0	68.0	7.3	1166700.	610000.
154-108	05/03/82	1415	14.0	67.0	7.3	866700.	510000.
155-109	05/04/82	0930	17.0	59.0	7.3	600000.	667700.
155-110	05/04/82	1200	14.0	37.0	7.3	1066700.	690000.
155-111	05/04/82	1430	13.0	35.0	7.4	1900000.	766700.
156-112	05/05/82		3.0	47.0	7.3	1183300.	778300.
156-113	05/05/82		4.0	38.0	7.4	631700.	603300.
157-114	05/06/82	0930	4.2	36.0	7.2	540000.	660000.
157-115	05/06/82	1100	.5	72.0	7.2	280000.	610000.
157-116	05/06/82	1330	5.0	73.0	7.2	1366700.	600000.
161-117	05/10/82	1230	1.1	36.0	7.7	320000.	120000.
161-118	05/10/82	1430	4.5	48.0	7.3	686700.	300000.
162-119	05/11/82		2.7	28.0	7.5	1233300.	203300.
168-120	05/17/82		*****	21.0	7.7	2100000.	733300.
169-121	05/18/82	1100	3.2	21.0	7.4	2500000.	1000000.
169-122	05/18/82	1330	2.5	33.0	7.2	2016700.	1366700.
171-123	05/20/82	1030	2.1	21.0	7.0	966700.	320000.
176-124	05/25/82	1000	1.2	7.0	7.5	210000.	73300.
176-125	05/25/82	1230	1.1	10.0	7.3	300000.	118300.
176-126	05/25/82	1500	1.6	11.0	7.3	498900.	220000.
177-127	05/26/82	1000	1.6	19.0	7.5	160000.	100000.
177-128	05/26/82	1200	1.4	14.0	7.5	166700.	70000.
177-129	05/26/82	1500	1.2	23.0	7.4	695000.	430000.
183-130	06/01/82	1000	0.6	13.0	7.1	180000.	70000.
183-131	06/01/82	1230	0.5	16.0	7.1	160000.	96700.
183-132	06/01/82	1450	0.1	18.0	7.1	380000.	116700.
196-133	06/14/82		0.2	13.6	6.6	460000.	100000.
196-134	06/14/82		0.1	8.4	6.7	345000.	113300.
196-135	06/14/82		0.1	10.0	6.7	481300.	281700.
197-136	06/15/82	1130	0.1	6.4	7.0	600000.	263300.
197-137	06/15/82	1430	0.2	5.2	6.8	680000.	430000.
197-138	06/15/82	1600	0.4	6.0	6.8	933300.	510000.
198-139	06/16/82	1200	1.0	7.0	7.0	1333300.	766700.
198-140	06/16/82	1400	0.5	6.0	7.1	1233300.	766700.
198-141	06/16/82	1615	0.4	8.0	7.0	1366700.	833300.
203-142	06/21/82	1130	1.4	16.0	7.4	220000.	110000.
203-143	06/21/82	1330	0.8	20.0	7.6	340000.	215000.
203-144	06/21/82	1530	1.0	5.0	7.3	442200.	214400.

Table 2. (Continued)

CODE	DATE	TIME	TURBIDITY (NTU)	SS (MG/L)	PH	TOTAL COLIFORM (COL/100ML)	FECAL COLIFORM (COL/100ML)
204-145	06/22/82	1030	1.1	12.0	7.6	315000.	201700.
204-146	06/22/82	1315	1.2	12.0	7.6	605000.	290000.
204-147	06/22/82	1600	0.9	10.0	7.5	816700.	415000.
205-148	06/23/82	1015	1.1	4.0	7.4	245000.	106700.
205-149	06/23/82	1230	1.2	6.0	7.2	295000.	144400.
205-150	06/23/82	1500	1.4	10.0	7.3	950000.	320000.
210-151	06/28/82	0930	0.9	10.0	7.1	753300.	445000.
210-152	06/28/82	1100	0.7	11.0	7.2	625600.	335000.
210-153	06/28/82	1330	0.8	11.0	7.2	7208300.	3466700.
211-154	06/29/82	0815	1.6	7.0	6.7	1116700.	450000.
211-155	06/29/82	1115	1.0	4.0	6.7	766700.	258900.
211-156	06/29/82	1330	1.6	10.0	6.7	1566700.	340000.
212-157	06/30/82	0830	0.7	4.0	7.2	698900.	223300.
212-158	06/30/82	1100	0.6	5.0	7.2	1150000.	275000.
212-159	06/30/82	1330	0.7	5.0	7.2	1250000.	530000.
218-160	07/06/82	0900	*****	8.0	7.3	690000.	344000.
218-161	07/06/82	1115	*****	6.4	7.1	500000.	250000.
218-162	07/06/82	1330	*****	4.4	7.2	705000.	405000.
219-163	07/07/82	1200	*****	2.4	7.1	933330.	423300.
225-164	07/13/82	0900	0.7	2.4	7.9	1855560.	687780.
225-165	07/13/82	1115	0.7	4.0	7.8	1383340.	653330.
225-166	07/13/82	1400	1.5	4.8	7.1	2941670.	1066670.
226-167	07/14/82	0900	1.3	3.6	7.7	1500000.	518890.
226-168	07/14/82	1130	*****	4.4	7.5	1266670.	405000.
226-169	07/14/82	1400	0.8	4.0	7.7	1816670.	585000.
231-170	07/19/82	0930	0.9	3.6	7.4	701670.	224450.
231-171	07/19/82	1200	1.8	5.6	7.2	822220.	440000.
231-172	07/19/82	1430	0.5	3.6	7.4	783330.	380000.
239-173	07/27/82	0900	0.8	2.4	7.1	630000.	500000.
239-174	07/27/82	1130	0.4	4.0	6.8	593330.	610000.
239-175	07/27/82	1400	1.5	3.6	6.7	835000.	485000.
240-176	07/28/82	0830	1.6	2.4	6.7	845000.	1015000.
240-177	07/28/82	1100	0.3	3.2	6.6	793330.	620000.
240-178	07/28/82	1400	1.2	3.2	7.4	1250000.	765000.
241-179	07/29/82	0830	0.4	2.0	7.0	622500.	475000.
245-180	08/02/82	0900	0.3	1.2	6.7	250000.	155000.
245-181	08/02/82	1100	0.6	1.6	6.7	180000.	165000.
245-182	08/02/82	1330	0.5	10.0	6.6	280000.	200000.
246-183	08/03/82	0900	0.8	3.2	6.7	672500.	395000.
246-184	08/03/82	1115	0.6	1.6	6.6	730000.	587500.
246-185	08/03/82	1330	1.5	2.8	6.6	1555000.	760000.
247-186	08/04/82	0900	0.9	3.6	7.3	915000.	355000.
247-187	08/04/82	1130	0.6	3.6	6.9	717500.	320000.
247-188	08/04/82	1400	1.1	4.8	7.1	860000.	440000.
252-189	08/09/82	0900	0.5	10.8	6.7	1500000.	474500.
252-190	08/09/82	1130	1.1	9.6	7.2	1400000.	753330.
252-191	08/09/82	1430	0.8	9.6	7.1	2175000.	1200000.
253-192	08/10/82	0900	0.5	9.2	7.6	**********	5200000.

Table 2. (Continued)

CODE	DATE	TIME	TURBIDITY (NTU)	SS (MG/L)	PH	TOTAL COLIFORM (COL/100ML)	FECAL COLIFORM (COL/100ML)
253-193	08/10/82		0.7	10.4	7.7	***********	2850000.
253-194	09/10/82	1330	0.5	9.2	7.3	***********	3600000.
254-195	08/11/82	1015	0.9	6.4	7.2	***********	1133330.
254-196	08/11/82	1200	0.5	5.2	7.2	***********	1133330.
254-197	08/11/82	1400	0.6	5.6	7.2	***********	1000000.
260-198	08/17/82	1150	0.2	2.0	7.3	3450000.	1200000.
260-199	08/17/82	1300	0.4	4.0	7.3	2341700.	220000.
266-200	08/23/82	0940	0.6	2.3	7.7	516670.	213300.
266-201	08/23/82	1135	0.4	1.7	7.7	610000.	160000.
266-202	08/23/82	1345	0.3	1.7	7.8	465000.	300000.
267-203	08/24/82	0930	0.6	2.2	8.9	737800.	230000.
267-204	08/24/82	1145	0.7	0.6	9.0	520000.	226700.
267-205	08/24/82	1410	*****	0.6	7.1	1183300.	265000.
268-206	08/25/82	0920	0.5	5.6	8.0	3250000.	1891700.
268-207	08/25/82	1145	1.5	23.6	7.8	6483300.	2777800.
268-208	08/25/82	1420	1.5	21.2	7.8	5450000.	4150000.
274-209	08/31/82		0.6	2.8	8.0	2050000.	156700.
275-210	09/01/82	0900	0.6	4.0	8.0	833300.	360000.
275-211	09/01/82	1100	0.6	3.2	9.9	650000.	204450.
275-212	09/01/82	1400	0.2	4.0	7.9	866700.	158300.
281-213	09/07/82	1200	0.2	3.5	7.0	733300.	540000.
281-214	09/07/82	1330	0.4	4.0	7.5	725000.	405000.
282-215	09/08/82	1130	1.7	3.0	7.7	670000.	240800.
282-216	09/08/82		0.5	9.5	7.8	974400.	565000.
282-217	09/08/82		*****	9.0	****	1216700.	298000.
296-218	09/22/82	1200	0.8	7.0	7.6	1666700.	540000.
308-219	10/04/82	1330	0.3	8.4	7.6	916700.	715000.
308-220	10/04/82	1600	1.5	8.0	7.6	1100000.	866700.
309-221	10/05/82		1.5	7.2	7.5	460000.	128900.
309-222	10/05/82		0.7	7.6	7.2	933330.	716700.
310-223	10/06/82	1100	1.5	4.8	7.4	770000.	460000.
310-224	10/06/82	1400	0.8	6.0	7.5	893330.	370000.
315-225	10/12/82	1130	*****	10.8	7.5	380000.	196700.
315-226	10/12/82	1515	*****	10.8	7.5	621700.	200000.
316-227	10/13/82	CSO	*****	*****	****	***********	***********
321-228	10/18/82	1200	*****	10.0	7.3	966700.	1166700.
321-229	10/18/82	1400	0.4	10.4	7.2	270000.	46700.
321-230	10/18/82	1600	1.3	9.6	7.8	490000.	1188300.
322-231	10/19/82		7.5	5.2	7.5	***********	***********
322-232	10/19/82		1.0	6.0	7.5	593300.	113300.
322-233	10/19/82		1.5	4.4	7.3	280000.	90000.
329-234	10/25/82	CSO	*****	*****	****	***********	***********
329-235	10/25/82	CSO	*****	*****	****	***********	***********
329-236	10/25/82	CSO	*****	*****	****	***********	***********
330-237	10/26/82		2.4	9.2	7.2	866700.	545000.
331-238	10/27/82	1130	1.4	8.0	7.1	1466700.	670000.
331-239	10/27/82	1330	1.0	4.8	7.6	1522200.	620000.
337-240	11/02/82	1100	1.8	42.0	8.1	***********	***********

Table 2. (Continued)

CODE	DATE	TIME	TURBIDITY (NTU)	SS (MG/L)	PH	TOTAL COLIFORM (COL/100ML)	FECAL COLIFORM (COL/100ML)
337-241	11/02/82	1300	7.6	28.0	7.6	***********	***********
337-242	11/02/82	1500	1.8	35.0	8.0	***********	***********
338-243	11/03/82	1030	2.3	32.0	7.7	***********	***********
338-244	11/03/82	1300	2.8	26.0	7.5	***********	***********
338-245	11/03/82	1500	3.8	30.0	6.9	***********	***********
343-246	11/08/82		1.1	20.0	6.9	907800.	355000.
343-247	11/08/82		1.5	16.0	7.2	1100000.	540000.
345-248	11/10/82	1100	0.5	17.5	7.0	395000.	120000.
345-249	11/10/82		0.5	13.5	7.0	350000.	100000.
350-250	11/15/82	1130	0.2	2.8	7.5	330000.	130000.
350-251	11/15/82	1415	0.2	2.4	7.3	372500.	700000.
351-252	11/16/82	1100	0.6	7.6	7.4	2977800.	736700.
351-253	11/16/82	1445	0.4	14.0	7.2	6950000.	1833300.
352-254	11/17/82	1130	0.3	6.8	7.4	1300000.	560000.
352-255	11/17/82	1430	0.2	4.8	7.2	1767700.	2650000.
353-256	11/18/82	1200	0.2	5.6	7.6	3800000.	1250000.
353-257	11/18/82		0.3	7.2	7.4	2000000.	56700.
357-258	11/22/82	1100	0.3	4.8	7.2	6050000.	1200000.
357-259	11/22/82	1430	7.5	4.0	7.5	4850000.	1725000.
357-259A	11/22/82	1430	*****	*****	****	***********	***********
358-260	11/23/82	1130	2.1	14.4	7.0	3250000.	2935000.
358-261	11/23/82	1430	2.1	12.0	7.0	7250000.	2000000.
358-261A	11/23/82	1430	*****	*****	****	***********	***********
364-262	11/29/82		1.1	12.0	6.6	1400000.	3650000.
364-263	11/29/82	1300	1.0	11.6	6.1	1500000.	620000.
364-264	11/29/82	1500	0.9	10.4	6.3	1600000.	735000.
365-265	11/30/82	1330	1.4	8.0	7.1	2400000.	875000.
366-266	12/01/82	1230	1.2	13.2	7.0	5500000.	690000.
367-267	12/02/82	1200	1.1	9.6	6.6	700000.	210000.
367-268	12/02/82	1415	1.1	12.8	7.0	945000.	436700.
367-269	12/02/82	1530	1.1	13.6	7.1	800000.	560000.
371-270	12/06/82	1230	2.4	7.6	7.4	580000.	230000.
371-271	12/06/82	1415	2.2	8.8	7.5	695000.	340000.
371-272	12/06/82	1600	0.7	7.2	7.6	660000.	160000.
372-273	12/07/82	1200	2.5	8.8	7.4	675000.	170000.
372-274	12/07/82	1415	2.4	10.4	7.4	***********	***********
372-275	12/07/82		*****	*****	****	***********	***********
373-276	12/08/82	1130	2.8	4.8	7.4	2000000.	183300.
373-277	12/08/82		2.4	5.6	7.4	1476700.	301700.
373-278	12/08/82		1.8	5.6	7.4	927500.	280000.
378-279	12/13/82	1200	1.9	10.0	7.3	576700.	123500.
378-280	12/13/82		2.5	10.0	7.4	760000.	145000.
378-281	12/13/82		2.4	11.6	7.4	732500.	216700.
379-282	12/14/82	1130	3.0	8.8	7.6	800000.	150000.
379-283	12/14/82		2.2	12.0	7.7	1016700.	345000.
379-284	12/14/82		1.9	12.8	7.3	933300.	281700.
380-285	12/15/82	1500	7.5	13.6	7.4	1775000.	787500.
381-286	12/16/82	CSO	*****	*****	****	***********	***********

Table 2. (Continued)

CODE	DATE	TIME	TURBIDITY (NTU)	SS (MG/L)	PH	TOTAL COLIFORM (COL/100ML)	FECAL COLIFORM (COL/100ML)
381-287	12/16/82	CSO	*****	*****	****	**********	**********
385-288	12/20/82		3.5	21.2	6.9	2950000.	1300000.
385-289	12/20/82		2.5	15.6	7.1	3400000.	1450000.
385-290	12/20/82		2.4	15.6	7.0	3850000.	1250000.
385-291	12/20/82		3.2	16.8	7.1	3200000.	1700000.
386-292A	12/21/82		6.2	16.0	7.0	2700000.	873300.
386-292B	12/21/82		6.2	16.0	7.0	2700000.	873300.
386-293A	12/21/82		10.0	19.2	6.9	5500000.	1450000.
386-293B	12/21/82		10.0	19.2	6.9	5500000.	1450000.
399-294	01/03/83		290.0	580.0	7.6	25667000.	1300000.
399-295	01/03/83		22.0	51.0	7.8	1400000.	197000.
400-296	01/04/83	1130	3.2	9.2	7.6	587500.	144300.
400-297A	01/04/83	1330	4.0	10.4	7.9	965000.	295000.
400-297B	01/04/83	1330	4.0	10.4	7.9	965000.	295000.
400-298A	01/04/83	1600	4.2	12.0	7.8	776700.	370000.
400-298B	01/04/83	1600	4.2	12.0	7.8	776700.	370000.
401-299	01/05/83		4.2	11.0	7.7	1200000.	270000.
401-300A	01/05/83		4.2	8.8	7.7	960000.	310000.
401-300B	01/05/83		4.2	8.8	7.7	960000.	310000.
402-3011	01/06/83	1100	3.7	6.4	7.3	787500.	226700.
402-3012	01/06/83	1100	3.7	6.4	7.3	787500.	226700.
402-302	01/06/83	1300	5.2	5.6	7.5	1000000.	223300.
402-3031	01/06/83	1500	3.2	7.2	7.6	1250000.	325000.
402-3032	01/06/83	1500	3.2	7.2	7.6	1250000.	325000.
406-304	01/10/83		3.0	10.4	7.4	2400000.	300000.
407-305	01/11/83		2.7	7.2	7.7	2333300.	345000.
407-3051	01/11/83		2.7	7.2	7.7	2333300.	345000.
407-3052	01/11/83		2.7	7.2	7.7	2333300.	345000.
408-306	01/12/83	1130	2.5	4.0	7.4	2375000.	275000.
408-307	01/12/83	1600	2.6	6.4	7.4	2425000.	460000.
409-308	01/13/83		25.0	36.0	7.0	7470000.	2266700.
409-309	01/13/83		7.5	27.0	7.5	8033300.	2175000.
413-310	01/17/83	1500	3.4	13.6	7.8	9025000.	3650000.
414-311	01/18/83	1100	5.5	16.0	7.6	17000000.	285000.
414-312	01/18/83	1400	5.0	20.5	7.4	12500000.	2250000.
415-313	01/19/83	1200	8.0	15.5	7.4	18000000.	1850000.
415-314	01/19/83	1500	8.3	18.5	7.5	9000000.	2000000.
416-315	01/20/83	1200	19.0	20.5	7.3	33500000.	2200000.
416-316	01/20/83	1500	8.2	12.5	7.5	13500000.	3300000.
420-317	01/24/83	1300	6.0	22.4	7.6	2530000.	730000.
420-318	01/24/83	1600	6.0	21.0	7.6	3450000.	746000.
421-319	01/25/83	1100	9.4	24.0	7.5	3050000.	440000.
421-320	01/25/83	1330	5.5	20.0	7.6	3200000.	800000.
421-321	01/25/83	1500	7.5	19.0	7.7	3200000.	965000.
422-322	01/26/83	1230	9.0	30.0	7.6	3200000.	630000.
422-323	01/26/83	1630	9.5	*****	7.8	4600000.	830000.
423-324	01/27/83	1230	8.5	27.0	7.6	1930000.	460000.
423-325	01/27/83	1530	7.2	24.0	7.7	1825000.	500000.

Table 2. (Continued)

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*   CODE    * *  DATE   *  *TIME*  *TURBIDITY*  *  SS   * *  PH   *  *  TOTAL     * *  FECAL     *
*           * *         *  *    *  *          *  *       * *       *  *COLIFORM    * * COLIFORM   *
*           * *         *  *    *  * ( NTU )  *  *(MG/L)* *       *  *(COL/100ML)* *(COL/100ML)*
  427-326     01/31/83     1145         9.8        81.0       7.8       1050000.       160000.
  427-327     01/31/83     1330         9.5        70.0       7.8       1150000.       130000.
  427-328     01/31/83     1600         5.5        65.0       7.8        985000.       190000.
  428-329     02/01/83     1130         6.8        22.0       7.6      11000000.       233000.
  428-330     02/01/83     1330         8.0        22.0       7.5        560000.        95000.
  428-331     02/01/83     1700         7.2        20.0       7.5        785000.        98500.
  429-332     02/02/83     1100         6.2        20.8       7.5       1450000.       154000.
  429-333     02/02/83     1500         6.5        21.2       7.5       1400000.       240000.
  430-334     02/03/83     1200         9.0        22.4       7.4        555000.       230000.
  430-335     02/03/83     1430        22.0        20.0       7.4        805000.       135000.
  441-336     02/09/83                  5.5        22.0       7.5       2100000.       900000.
  444-337     02/17/83     1200         6.5        37.6       7.5       1650000.       496700.
  444-338     02/17/83                  5.0        28.0       7.6       2125000.       865000.
  455-339     02/28/83                  9.5        26.0       7.9       1833300.       650000.
  455-340     02/28/83                  6.0        34.0       7.8       1900000.       555000.
  462-341     03/07/83     1100         8.5        25.0       7.6       3250000.      1300000.
  462-342     03/07/83     1230         9.0        18.0       7.8       2633000.      1050000.
  462-343     03/07/83     1430         5.5        13.5       7.7       3000000.       870000.
  463-344     03/08/83     1115         5.5        14.0       7.5       2733300.      1015000.
  463-345     03/08/83     1230         6.0        13.6       7.5       2625000.      1300000.
  463-346     03/08/83      CSO       *****       *****      ****    ***********    **********
  464-347     03/09/83                  7.0        21.0       7.7       2225000.      1100000.
  464-348     03/09/83                  7.0        20.5       7.7       2025000.       935000.
  464-349     03/09/83                  7.0        22.5       7.7       2525000.       885000.
  469-350     03/14/83     1200         6.0        14.4       7.7        405000.       235000.
  469-351     03/14/83     1400         4.5        12.8       8.0        455000.       160000.
  470-352     03/15/83                  7.0        15.6       7.9        435000.       285000.
  470-353     03/15/83                  3.8        12.0       7.8        360000.       170000.
  471-354     03/16/83     1130         7.0         7.2       7.7        385000.       105000.
  471-355     03/16/83     1430         6.5        10.8       7.7        410000.       195400.
  472-356     03/17/83     1130         7.8         6.3       7.6        260000.       103300.
  472-357     03/17/83     1500         7.8        11.6       7.6        360000.       170000.
  476-358     03/21/83      CSO       *****       *****      ****    ***********    **********
  476-359     03/21/83      CSO       *****       *****      ****    ***********    **********
  477-360     03/22/83                  7.0         8.4       7.5        355000.       210000.
  477-361     03/22/83     1500         6.5        18.8       7.7        550000.       235000.
  478-362     03/23/83     1430         4.5         6.8       7.5        370000.       155000.
  479-363     03/24/83     1100         3.5        14.0       7.6        355000.       157800.
  483-364     03/28/83     1130        22.0        34.0       7.6        435000.       140000.
  483-365     03/28/83     1500         4.5        11.2       7.8        340000.       133300.
  484-366     03/29/83     1130         5.5         7.2       7.5        125000.        53000.
  484-367     03/29/83     1500         4.5         6.4       7.5        245000.       110000.
  497-368     04/11/83                  4.5         7.2       7.6        780000.       300000.
  497-369     04/11/83                  2.5         8.8       7.7        590000.       230000.
  497-370     04/11/83                  2.5        10.0       7.7        516700.       200000.
  498-371     04/12/83     1030         3.5        13.2       7.7        455000.       115000.
  498-372     04/12/83     1300         3.5        10.0       7.7        435000.       120000.
  498-373     04/12/83     1600         3.0         6.6       7.8        425000.       187800.
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Table 2. (Continued)

CODE	DATE	TIME	TURBIDITY (NTU)	SS (MG/L)	PH	TOTAL COLIFORM (COL/100ML)	FECAL COLIFORM (COL/100ML)
499-374	04/13/83		3.5	11.2	7.8	756700.	252500.
499-375	04/13/83		3.5	7.2	7.8	405000.	205000.
499-376	04/13/83		2.0	4.4	7.7	600000.	191100.
500-377	04/14/83	0800	12.0	44.0	7.7	458000.	350000.
500-378	04/14/83	0925	5.0	13.6	7.7	670000.	380000.
500-379	04/14/83	1100	3.0	9.2	7.7	735000.	455000.
500-380	04/14/83	1415	4.0	15.2	7.8	793300.	496700.
500-381	04/14/83	1515	3.5	6.4	7.8	887500.	670000.
500-382	04/14/83	1600	3.0	6.8	8.0	**********	**********
504-383	04/18/83	1300	7.7	10.0	7.7	460000.	266700.
504-384	04/18/83	1500	3.5	10.8	7.7	510000.	275000.
504-385	04/18/83	1700	4.5	9.2	7.8	665000.	315000.
505-386	04/19/83	1200	3.5	11.2	7.7	750000.	430000.
505-387	04/19/83	1400	3.0	3.2	7.5	470000.	430000.
505-388	04/19/83	1600	6.5	16.0	7.5	566700.	275000.
506-389	04/20/83		3.5	7.6	7.4	365000.	370000.
506-390	04/20/83		3.0	8.8	7.4	480000.	200000.
506-391	04/20/83		3.5	9.2	7.5	685000.	365000.
507-392	04/21/83		7.5	11.2	7.2	623000.	360000.
507-393	04/21/83		4.5	14.0	7.2	576700.	206700.
507-394	04/21/83		5.0	10.8	7.2	530000.	296700.
507-395	04/21/83		3.5	9.2	7.2	590000.	193300.
507-396	04/21/83		3.5	11.2	7.3	450000.	193300.
507-397	04/21/83		5.0	13.2	7.4	670000.	330000.
511-398	04/25/83	1100	*****	12.0	****	262500.	78500.
511-399	04/25/83	1200	3.5	12.8	7.2	210000.	110000.
511-400	04/25/83	1500	*****	50.8	****	535000.	245000.
512-401	04/26/83	1230	*****	13.6	****	533300.	253300.
512-402	04/26/83	1400	3.2	6.0	7.2	420000.	216700.
512-403	04/26/83	1530	*****	8.0	****	475000.	256700.
513-404	04/27/83	1000	*****	7.6	****	260000.	206700.
513-405	04/27/83	1130	4.5	9.2	7.7	290000.	90000.
513-406	04/27/83	1530	*****	6.8	****	270000.	145000.
514-407	04/28/83	1100	*****	18.8	****	360000.	205000.
514-408	04/28/83	1300	6.5	26.0	7.3	380000.	153300.
514-409	04/28/83	1500	*****	10.4	****	385000.	120000.
520-410	05/04/83	1100	*****	5.0	****	1825000.	833300.
520-411	05/04/83	1300	6.2	6.5	7.4	1850000.	440000.
520-412	05/04/83	1530	*****	18.0	****	2367700.	536700.
521-413	05/05/83	1200	*****	24.0	****	1825000.	670000.
521-414	05/05/83	1330	9.5	19.0	7.8	1800000.	605000.
521-415	05/05/83	1500	*****	20.5	****	2583300.	1100000.
574-416	06/27/83		2.2	4.4	6.9	690000.	360000.
574-417	06/27/83		1.8	3.0	6.9	540000.	350000.
574-418	06/27/83		1.8	4.0	7.2	970000.	380000.
575-419	06/28/83		1.3	1.4	7.3	520000.	200000.
575-420	06/28/83		1.1	2.0	7.2	690000.	250000.
575-421	06/28/83		1.4	2.2	7.1	1100000.	470000.

Table 2. (Continued)

CODE	DATE	TIME	TURBIDITY (NTU)	SS (MG/L)	PH	TOTAL COLIFORM (COL/100ML)	FECAL COLIFORM (COL/100ML)
576-422	06/29/83		2.8	5.6	6.6	23000000.	19000000.
576-423	06/29/83		1.5	10.4	6.5	24000000.	13000000.
576-424	06/29/83		1.6	8.8	6.8	24000000.	21000000.
577-425	06/30/83		1.7	6.4	7.0	4700000.	6300000.
577-426	06/30/83		1.5	6.4	6.9	6400000.	5100000.
577-427	06/30/83		1.4	6.8	7.0	6400000.	4500000.
589-428	07/12/83	1100	5.8	17.2	7.0	355000.	110000.
589-429	07/12/83	1300	4.3	15.2	7.1	480000.	210000.
589-430	07/12/83	1515	4.2	17.2	7.1	800000.	580000.
590-431	07/13/83	1100	3.9	10.0	7.2	1900000.	1950000.
590-432	07/13/83	1315	4.2	10.0	7.1	2650000.	1500000.
590-433	07/13/83	1530	4.1	10.4	7.0	4400000.	2066700.
591-434	07/14/83		7.1	13.6	7.1	7150000.	2800000.
591-435	07/14/83		3.0	12.8	7.1	9400000.	3050000.
591-436	07/14/83		3.0	14.0	7.2	10170000.	3900000.
595-437	07/18/83	1000	3.5	10.0	6.9	200000.	70000.
595-438	07/18/83	1215	3.5	8.0	6.9	**********	120000.
595-439	07/18/83	1500	3.2	11.2	7.0	310000.	245000.
596-440	07/19/83	1030	4.0	16.4	6.9	4000000.	3650000.
596-441	07/19/83	1330	4.2	17.6	6.9	6000000.	2000000.
597-442	07/20/83	1100	6.2	18.0	7.0	16333300.	8666700.
602-443	07/25/83	1200	5.2	25.6	6.9	23000000.	14000000.
602-444	07/25/83	1530	6.2	31.6	7.3	21000000.	17000000.
603-445	07/26/83	1005	6.4	26.8	7.1	21000000.	**********
603-446	07/26/83	1300	6.5	23.6	7.3	16500000.	16000000.
603-447	07/26/83	1615	8.4	6.4	7.2	21500000.	9300000.
604-448	07/27/83	0845	6.8	24.8	7.3	7500000.	6100000.
604-449	07/27/83	1130	8.5	30.0	7.3	7850000.	4900000.
604-450	07/27/83		8.0	28.4	7.2	8300000.	4750000.
605-451	07/28/83		9.5	33.5	7.1	6875000.	3100000.
605-452	07/28/83		9.8	30.5	7.3	10166700.	3850000.
605-453	07/28/83		8.5	25.0	7.3	9300000.	5333300.
609-454	08/01/83	1000	4.0	10.8	7.4	295000.	180000.
609-455	08/01/83	1130	4.8	8.0	7.0	220000.	**********
609-456	08/01/83	1400	3.0	8.0	7.5	280000.	170000.
610-457	08/02/83	0930	4.2	7.6	7.4	70000.	46700.
610-458	08/02/83	1115	3.2	8.8	7.1	91700.	40000.
610-459	08/02/83	1500	4.0	6.8	7.3	140000.	63300.
611-460	08/03/83	0930	3.8	2.8	6.8	365000.	**********
611-461	08/03/83	1230	4.0	4.0	7.0	390000.	214400.
611-462	08/03/83	1500	3.2	5.6	7.1	843300.	415000.
612-463	08/04/83	0945	3.8	8.4	6.8	410000.	212200.
612-464	08/04/83	1330	4.0	12.0	7.1	1650000.	690000.
612-465	08/04/83	1345	3.8	9.6	6.1	1750000.	**********
616-466	08/08/83	0935	3.0	2.0	7.7	186700.	160000.
616-467	08/08/83	1145	4.4	3.6	7.3	163300.	110000.
616-468	08/08/83	1500	3.8	3.6	7.5	390000.	182200.
617-469	08/09/83	0945	3.8	2.4	7.4	217500.	56200.

Table 2. (Continued)

CODE	DATE	TIME	TURBIDITY (NTU)	SS (MG/L)	PH	TOTAL COLIFORM (COL/100ML)	FECAL COLIFORM (COL/100ML)
617-470	08/09/83	1200	4.0	2.2	7.3	194400.	125000.
617-471	08/09/83	1500	5.2	3.8	7.6	635600.	365000.
618-472	08/10/83	1000	4.2	4.6	7.3	113300.	40000.
618-473	08/10/83	1200	3.0	4.2	7.3	171700.	73500.
618-474	08/10/83	1400	4.4	6.4	7.3	515000.	200000.
619-475	08/11/83	0925	5.4	8.8	7.3	127700.	100000.
619-476	08/11/83	1130	3.2	9.2	7.2	176700.	67500.
619-477	08/11/83	1430	5.5	10.4	7.2	285000.	106500.
630-478	08/22/83	1000	3.5	4.4	6.9	245000.	205000.
630-479	08/22/83	1200	1.6	4.4	7.0	235000.	320000.
631-480	08/23/83	1000	4.5	5.6	7.4	173300.	80000.
631-481	08/23/83	1200	2.1	8.4	7.2	160000.	57000.
632-482	08/24/83		4.0	8.0	7.4	270000.	163300.
632-483	08/24/83		2.2	7.6	7.2	266700.	135000.
633-484	08/25/83	1000	5.2	6.6	7.7	275000.	150000.
633-485	08/25/83	1330	2.5	6.8	7.2	985800.	295000.

Table 2. (Continued)

CODE	DATE	TIME	DIRECT UV TOTAL (CM-1)	UIRECT UV FILTER (CM-1)	SPHERE UV TOTAL (CM-1)	SPHERE UV FILTER (CM-1)
U02-001	12/02/81	0930	0.334	U.313	0.313	0.304
U02-002	12/02/81	1045	0.340	U.315	0.311	0.306
U02-003	12/02/81	1200	0.329	U.334	0.315	0.315
U02-004	12/02/81	1430	0.329	U.343	0.329	0.324
U03-005	12/03/81	0830	0.400	U.347	0.343	0.329
U03-006	12/03/81	1045	0.435	U.396	0.350	0.361
U03-007	12/03/81	1130	0.446	U.377	0.352	0.354
U03-008	12/03/81	1300	0.458	U.370	0.359	0.350
U07-009	12/07/81	0930	0.304	U.253	0.278	0.248
U07-010	12/07/81	1350	0.317	U.267	0.281	0.246
U07-011	12/07/81		0.297	U.255	0.260	0.255
U14-012	12/14/81	0800	0.437	U.276	0.297	0.262
U14-013	12/14/81	1130	0.469	U.281	0.285	0.260
U14-014	12/14/81	1415	0.465	U.299	0.285	0.253
U15-015	12/15/81	1030	0.246	U.232	0.237	0.223
U15-016	12/15/81	1200	0.306	U.274	0.242	0.239
U15-017	12/15/81	1330	0.326	U.290	0.271	0.240
U16-018	12/16/81	1115	0.306	U.271	0.258	0.255
U16-019	12/16/81	1230	0.320	U.278	0.271	0.265
U17-020	12/17/81	0830	0.334	U.290	0.271	0.276
U17-021	12/17/81	1115	0.375	U.322	0.301	0.306
U17-022	12/17/81	1415	0.380	U.338	0.299	0.299
U21-023	12/21/81	0930	0.616	U.315	0.285	0.274
U21-024	12/21/81	1130	0.651	U.317	0.290	0.269
U21-025	12/21/81	1345	0.619	U.322	0.297	0.271
U23-026	12/23/81	1000	0.616	U.428	0.460	0.375
U23-027	12/23/81	1130	0.589	U.421	0.403	0.380
U23-028	12/23/81	1330	0.614	U.391	0.400	0.391
U28-029	12/28/81	0830	0.317	U.276	0.253	0.262
U28-030	12/28/81	1000	0.343	U.288	0.253	0.248
U28-031	12/28/81	1230	0.338	U.267	0.260	0.251
U29-032	12/29/81	0900	0.324	U.269	0.269	0.253
U29-033	12/29/81	1130	0.363	U.260	0.269	0.258
U29-034	12/29/81	1330	0.354	U.251	0.265	0.244
U35-035	01/04/82	1000	0.276	U.241	0.225	0.211
U35-036	01/04/82		0.248	U.223	0.202	0.202
U35-037	01/04/82		0.253	U.242	0.207	0.207
U35-038	01/04/82		0.267	U.281	0.232	0.237
U37-039	01/06/82	0700	0.412	U.409	0.368	0.380
U37-040	01/06/82	0930	0.400	U.396	0.354	0.366
U37-041	01/06/82	1200	0.460	0.439	0.412	0.426
U38-042	01/07/82	0700	0.497	U.439	0.432	0.441
U38-043	01/07/82	1200	0.630	U.446	0.437	0.446
U41-044	01/11/82	1330	0.417	U.313	0.281	0.281
U42-045	01/12/82	0945	0.598	U.340	0.327	0.308
U42-046	01/12/82	1115	0.609	U.350	0.350	0.317
U42-047	01/12/82	1400	0.552	U.377	0.340	0.324

Table 2A. Influent (Secondary) to UV Units - UV Absorbance

CODE	DATE	TIME	DIRECT UV TOTAL (CM-1)	DIRECT UV FILTER (CM-1)	SPHERE UV TOTAL (CM-1)	SPHERE UV FILTER (CM-1)
051-048	01/20/82	1015	1.150	0.892	0.931	0.768
051-049	01/20/82	1145	1.200	0.895	0.966	0.789
051-050	01/20/82	1315	1.120	1.000	0.941	0.812
058-051	01/27/82	0945	0.493	0.451	0.534	0.501
058-052	01/27/82	1145	0.458	0.446	0.531	0.478
058-053	01/27/82	1315	0.439	0.442	0.529	0.485
059-054	01/28/82	1000	0.653	0.469	0.432	0.421
059-055	01/28/82	1145	0.736	0.506	0.483	0.444
059-056	01/28/82	1330	0.805	0.515	0.497	0.448
066-057	02/04/82	1000	0.430	0.398	0.338	0.336
066-058	02/04/82	1330	0.375	0.359	0.329	0.315
071-059	02/09/82	1115	0.373	0.290	0.278	0.283
071-060	02/09/82	1400	0.396	0.304	0.297	0.290
072-061	02/10/82	0930	0.534	0.478	0.428	0.439
072-062	02/10/82	1130	0.580	0.467	0.455	0.442
072-063	02/10/82	1430	1.040	0.563	0.508	0.472
073-064	02/11/82	1030	0.6[illegible]3	0.481	0.471	0.449
073-065	02/11/82	1230	0.536	0.467	0.437	0.439
073-066	02/11/82	1430	0.547	0.453	0.421	0.437
078-067	02/16/82	1100	0.393	0.338	0.276	0.276
078-068	02/16/82	1330	0.343	0.315	0.251	0.258
079-069	02/17/82	1000	0.890	0.915	0.667	0.561
079-070	02/17/82	1145	0.918	0.892	0.685	0.605
079-071	02/17/82	1400	1.150	0.837	0.701	0.561
086-072	02/24/82	1000	0.708	0.731	0.550	0.517
086-073	02/24/82		0.814	0.766	0.644	0.559
087-074	02/25/82	1000	0.672	0.669	0.543	0.497
087-075	02/25/82	1400	0.626	0.596	0.499	0.449
091-076	03/01/82	1030	0.478	0.400	0.345	0.320
091-077	03/01/82	1230	0.380	0.380	0.304	0.297
091-078	03/01/82	1400	0.442	0.370	0.333	0.297
092-079	03/02/82	1000	0.506	0.444	0.409	0.377
092-080	03/02/82	1200	0.566	0.467	0.430	0.377
092-081	03/02/82	1400	0.637	0.426	0.490	0.375
093-082	03/03/82	1030	0.610	0.580	0.497	0.462
093-083	03/03/82	1230	0.637	0.543	0.476	0.439
093-084	03/03/82		0.557	0.492	0.446	0.430
094-085	03/04/82	1030	0.449	0.423	0.382	0.357
094-086	03/04/82	1230	0.472	0.400	0.382	0.343
094-087	03/04/82	1400	0.550	0.451	0.453	0.377
098-088	03/08/82	1115	0.345	0.304	0.306	0.276
098-089	03/08/82	1230	0.357	0.315	0.299	0.267
098-090	03/08/82	1430	0.359	0.340	0.322	0.283
099-091	03/09/82	1000	0.603	0.499	0.492	0.449
099-092	03/09/82	1200	0.559	0.557	0.469	0.446
099-093	03/09/82	1430	0.541	0.683	0.520	0.478
100-094	03/10/82	1115	0.469	0.495	0.490	0.405

Table 2A. (Continued)

CODE	DATE	TIME	DIRECT UV TOTAL (CM-1)	DIRECT UV FILTER (CM-1)	SPHERE UV TOTAL (CM-1)	SPHERE UV FILTER (CM-1)
100-095	03/10/82	1400	0.529	0.481	0.472	0.400
105-096	03/15/82	0915	0.340	0.146	0.306	0.258
105-097	03/15/82		0.338	0.324	0.271	0.265
106-098	03/16/82	0930	0.543	0.513	0.501	0.490
106-099	03/16/82	1200	0.451	0.391	0.405	0.359
106-100	03/16/82	1400	0.472	0.391	0.409	0.359
107-101	03/17/82	1130	0.386	0.398	0.354	0.324
107-102	03/17/82	1430	0.363	0.317	0.333	0.301
149-103	04/28/82	1015	0.697	0.474	0.467	0.373
149-104	04/28/82	1130	0.662	0.476	0.455	0.382
149-105	04/28/82	1330	0.727	0.499	0.513	0.393
150-106	04/29/82	1015	0.535	0.451	0.389	0.380
154-107	05/03/82	1200	0.481	0.377	0.338	0.308
154-108	05/03/82	1415	0.497	0.322	0.352	0.271
155-109	05/04/82	0930	0.635	0.435	0.474	0.386
155-110	05/04/82	1200	0.577	0.442	0.439	0.389
155-111	05/04/82	1430	0.541	0.430	0.414	0.384
156-112	05/05/82		0.607	0.485	0.483	0.432
156-113	05/05/82		0.674	0.508	0.485	0.435
157-114	05/06/82	0930	0.538	0.474	0.444	0.414
157-115	05/06/82	1100	0.697	0.527	0.513	0.442
157-116	05/06/82	1330	0.715	0.518	0.570	0.446
161-117	05/10/82	1230	0.508	0.453	0.334	0.334
161-118	05/10/82	1430	0.474	0.423	0.389	0.329
162-119	05/11/82		0.722	0.538	0.495	0.432
168-120	05/17/82		*****	0.400	*****	0.324
169-121	05/18/82	1100	0.713	0.584	0.467	0.458
169-122	05/18/82	1330	0.603	0.550	0.451	0.439
171-123	05/20/82	1030	0.584	0.504	0.451	0.393
176-124	05/25/82	1000	0.363	0.345	0.202	0.189
176-125	05/25/82	1230	0.386	0.347	0.214	0.173
176-126	05/25/82	1500	0.347	0.336	0.163	0.184
177-127	05/26/82	1000	0.428	0.373	0.198	0.198
177-128	05/26/82	1200	0.400	0.352	0.177	0.184
177-129	05/26/82	1500	0.405	0.359	0.198	0.196
183-130	06/01/82	1000	0.699	0.299	0.329	0.297
183-131	06/01/82	1230	0.665	0.359	0.322	0.278
183-132	06/01/82	1450	0.616	0.359	0.322	0.297
196-133	06/14/82		0.391	0.370	0.315	0.324
196-134	06/14/82		0.426	0.370	0.340	0.334
196-135	06/14/82		0.451	0.428	0.380	0.377
197-136	06/15/82	1130	0.426	0.382	0.352	0.359
197-137	06/15/82	1430	0.442	0.403	0.363	0.366
197-138	06/15/82	1600	0.437	0.393	0.363	0.366
198-139	06/16/82	1200	0.472	0.384	0.352	0.350
198-140	06/16/82	1400	0.492	0.384	0.354	0.347
198-141	06/16/82	1615	0.478	0.384	0.347	0.345

Table 2A. (Continued)

CODE	DATE	TIME	DIRECT UV TOTAL (CM-1)	DIRECT UV FILTER (CM-1)	SPHERE UV TOTAL (CM-1)	SPHERE UV FILTER (CM-1)
203-142	06/21/82	1130	0.541	0.315	0.274	0.241
203-143	06/21/82	1330	0.460	0.301	0.274	0.265
203-144	06/21/82	1530	0.474	0.308	0.290	0.274
204-145	06/22/82	1030	0.442	0.407	0.352	0.363
204-146	06/22/82	1315	0.522	0.382	0.359	0.359
204-147	06/22/82	1600	0.421	0.373	0.343	0.352
205-148	06/23/82	1015	0.430	0.472	0.414	0.437
205-149	06/23/82	1230	0.400	0.451	0.403	0.421
205-150	06/23/82	1500	0.446	0.451	0.400	0.407
210-151	06/28/82	0930	0.262	0.274	0.228	0.235
210-152	06/28/82	1100	0.278	0.244	0.230	0.230
210-153	06/28/82	1330	0.235	0.251	0.223	0.228
211-154	06/29/82	0815	0.368	0.382	0.370	0.373
211-155	06/29/82	1115	0.327	0.361	0.324	0.345
211-156	06/29/82	1330	0.320	0.338	0.299	0.322
212-157	06/30/82	0830	0.386	0.416	0.382	0.400
212-158	06/30/82	1100	0.391	0.423	0.386	0.407
212-159	06/30/82	1330	0.384	0.414	0.375	0.396
218-160	07/06/82	0900	*****	*****	*****	*****
218-161	07/06/82	1115	*****	*****	*****	*****
218-162	07/06/82	1330	*****	*****	*****	*****
219-163	07/07/82	1200	*****	*****	*****	*****
225-164	07/13/82	0900	0.414	0.380	0.343	0.324
225-165	07/13/82	1115	0.368	0.308	0.308	0.290
225-166	07/13/82	1400	0.345	0.317	0.290	0.288
226-167	07/14/82	0900	0.253	0.258	0.235	0.223
226-168	07/14/82	1130	0.246	0.246	0.212	0.214
226-169	07/14/82	1400	0.260	0.258	0.223	0.219
231-170	07/19/82	0930	0.230	0.242	0.207	0.209
231-171	07/19/82	1200	0.253	0.242	0.212	0.207
231-172	07/19/82	1430	0.221	0.239	0.205	0.209
239-173	07/27/82	0900	0.368	0.331	0.306	0.311
239-174	07/27/82	1130	0.345	0.324	0.294	0.301
239-175	07/27/82	1400	0.375	0.377	0.329	0.345
240-176	07/23/82	0830	0.421	0.421	0.350	0.368
240-177	07/28/82	1100	0.414	0.449	0.386	0.396
240-178	07/28/82	1400	0.453	0.490	0.419	0.442
241-179	07/29/82	0830	0.391	0.377	0.352	0.354
245-180	08/02/82	0900	0.221	0.225	0.221	0.223
245-181	08/02/82	1100	0.212	0.219	0.216	0.221
245-182	08/02/82	1330	0.214	0.232	0.221	0.228
246-183	08/03/82	0900	0.322	0.317	0.336	0.324
246-184	08/03/82	1115	0.396	0.398	0.400	0.398
246-185	08/03/82	1330	0.449	0.426	0.428	0.421
247-186	08/04/82	0900	0.403	0.428	0.412	0.412
247-187	08/04/82	1130	0.421	0.437	0.430	0.430
247-188	08/04/82	1400	0.451	0.455	0.458	0.449

Table 2A. (Continued)

CODE	DATE	TIME	DIRECT UV TOTAL (CM-1)	DIRECT UV FILTER (CM-1)	SPHERE UV TOTAL (CM-1)	SPHERE UV FILTER (CM-1)
252-189	08/09/82	0900	0.313	0.265	0.244	0.251
252-190	08/09/82	1130	0.327	0.269	0.253	0.248
252-191	08/09/82	1430	0.311	0.255	0.255	0.251
253-192	08/10/82	0900	0.531	0.416	0.414	0.405
253-193	08/10/82		0.481	0.412	0.386	0.398
253-194	08/10/82	1330	0.437	0.393	0.377	0.384
254-195	08/11/82	1015	0.460	0.430	0.405	0.423
254-196	08/11/82	1200	0.469	0.407	0.391	0.398
254-197	08/11/82	1400	0.444	0.389	0.384	0.386
260-198	08/17/82	1150	0.315	0.306	0.292	0.299
260-199	08/17/82	1300	0.329	0.313	0.292	0.304
266-200	08/23/82	0940	0.228	0.246	0.214	0.223
266-201	08/23/82	1135	0.248	0.251	0.212	0.219
266-202	08/23/82	1345	0.221	0.219	0.205	0.205
267-203	08/24/82	0930	0.317	0.347	0.299	0.301
267-204	08/24/82	1145	0.329	0.373	0.301	0.313
267-205	08/24/82	1410	0.327	0.320	0.281	0.299
268-206	08/25/82	0920	0.315	0.435	0.320	0.336
268-207	08/25/82	1145	0.421	0.386	0.363	0.354
268-208	08/25/82	1420	0.460	0.430	0.368	0.370
274-209	08/31/82		0.375	0.428	0.350	0.370
275-210	09/01/82	0900	0.382	0.359	0.308	0.317
275-211	09/01/82	1100	0.347	0.327	0.276	0.306
275-212	09/01/82	1400	0.331	0.345	0.311	0.290
281-213	09/07/82	1200	0.212	0.225	0.202	0.202
281-214	09/07/82	1330	0.221	0.219	0.202	0.207
282-215	09/08/82	1130	0.315	0.304	0.271	0.265
282-216	09/08/82		0.336	0.304	0.276	0.265
282-217	09/08/82		*****	*****	*****	*****
296-218	09/22/82	1200	0.403	0.460	0.513	0.536
308-219	10/04/82	1330	0.299	0.283	0.258	0.255
308-220	10/04/82	1600	0.368	0.265	0.246	0.258
309-221	10/05/82		0.403	0.306	0.359	0.363
309-222	10/05/82		0.341	0.311	0.352	0.347
310-223	10/06/82	1100	0.368	0.281	0.352	0.352
310-224	10/06/82	1400	0.352	0.324	0.363	0.359
315-225	10/12/82	1130	0.421	0.380	0.368	0.357
315-226	10/12/82	1515	0.407	0.368	0.347	0.345
316-227	10/13/82	CSO	*****	*****	*****	*****
321-228	10/18/82	1200	0.322	0.294	0.242	0.253
321-229	10/18/82	1400	0.366	0.271	0.251	0.255
321-230	10/18/82	1600	0.336	0.262	0.257	0.258
322-231	10/19/82		0.442	0.366	0.306	0.336
322-232	10/19/82		0.333	0.373	0.306	0.350
322-233	10/19/82		0.354	0.354	0.306	0.327
329-234	10/25/82	CSO	*****	*****	*****	*****
329-235	10/25/82	CSO	*****	*****	*****	*****

Table 2A. (Continued)

CODE	DATE	TIME	DIRECT UV TOTAL (CM-1)	UIRECT UV FILTER (CM-1)	SPHERE UV TOTAL (CM-1)	SPHERE UV FILTER (CM-1)
329-236	10/25/82	CSO	*****	*****	*****	*****
330-237	10/26/82		0.373	U.322	0.311	0.308
331-238	10/27/82	1130	0.340	U.359	0.267	0.322
331-239	10/27/82	1330	0.345	U.338	0.308	0.291
337-240	11/02/82	1100	0.513	U.380	0.317	0.336
337-241	11/02/82	1300	0.357	U.414	0.331	0.352
337-242	11/02/82	1500	0.416	U.382	0.366	0.363
338-243	11/03/82	1030	0.591	U.350	0.322	0.322
338-244	11/03/82	1300	0.729	U.458	0.458	0.437
338-245	11/03/82	1500	0.559	U.442	0.511	0.458
343-246	11/08/82		0.389	U.343	0.260	0.283
343-247	11/08/82		0.343	U.294	0.278	0.276
345-248	11/10/82	1100	0.444	U.435	0.366	0.386
345-249	11/10/82		0.350	U.419	0.366	0.384
350-250	11/15/82	1130	0.711	U.299	0.260	0.262
350-251	11/15/82	1415	0.317	U.306	0.269	0.283
351-252	11/16/82	1100	0.488	U.545	0.426	0.449
351-253	11/16/82	1445	0.573	U.557	0.437	0.462
352-254	11/17/82	1130	0.442	U.511	0.421	0.457
352-255	11/17/82	1430	0.469	U.458	0.428	0.439
353-256	11/18/82	1200	0.416	U.504	0.419	0.446
353-257	11/18/82		0.460	U.481	0.405	0.430
357-258	11/22/82	1100	0.359	U.347	0.260	0.299
357-259	11/22/82	1430	0.515	U.573	0.276	0.285
357-259A	11/22/82	1430	*****	*****	*****	*****
358-260	11/23/82	1130	0.446	U.478	0.340	0.524
358-261	11/23/82	1430	0.474	U.488	0.376	0.400
358-261A	11/23/82	1430	***.*	*****	*****	*****
364-262	11/29/82		0.301	U.320	0.265	0.281
364-263	11/29/82	1300	0.308	0.306	0.262	0.278
364-264	11/29/82	1500	0.308	U.299	0.262	0.276
365-265	11/30/82	1330	0.419	U.426	0.363	0.373
366-266	12/01/82	1230	0.545	U.573	0.495	0.534
367-267	12/02/82	1200	0.409	U.437	0.377	0.391
367-268	12/02/82	1415	0.398	0.419	0.359	0.380
367-269	12/02/82	1530	0.396	U.412	0.354	0.380
371-270	12/06/82	1230	0.352	U.324	0.281	0.299
371-271	12/06/82	1415	0.338	U.329	0.304	0.304
371-272	12/06/82	1600	0.354	U.324	0.308	0.304
372-273	12/07/82	1200	0.536	U.485	0.442	0.488
372-274	12/07/82	1415	0.543	U.522	0.495	0.490
372-275	12/07/82		*****	*****	*****	*****
373-276	12/08/82	1130	0.522	0.504	0.455	0.467
373-277	12/08/82		0.513	U.520	0.465	0.481
373-278	12/08/82		0.515	U.513	0.469	0.476
378-279	12/13/82	1200	0.294	U.274	0.253	0.253
378-280	12/13/82		0.290	U.283	0.260	0.265

Table 2A. (Continued)

CODE	DATE	TIME	DIRECT UV TOTAL (CM-1)	DIRECT UV FILTER (CM-1)	SPHERE UV TOTAL (CM-1)	SPHERE UV FILTER (CM-1)
378-281	12/13/82		0.278	0.278	0.253	0.260
379-282	12/14/82	1130	0.520	0.437	0.426	0.274
379-283	12/14/82		0.435	0.338	0.409	0.311
379-284	12/14/82		0.416	0.483	0.380	0.423
380-285	12/15/82	1500	0.557	0.559	0.492	0.511
381-286	12/16/82	CSO	*****	*****	*****	*****
381-287	12/16/82	CSO	*****	*****	*****	*****
385-288	12/20/82		0.265	0.260	0.248	0.294
385-289	12/20/82		0.244	0.237	0.262	0.255
385-290	12/20/82		0.251	0.237	0.253	0.258
385-291	12/20/82		0.260	0.244	0.274	0.271
386-292A	12/21/82		0.472	0.444	0.430	0.442
386-292B	12/21/82		0.472	0.444	0.430	0.442
386-293A	12/21/82		0.662	0.598	0.587	0.612
386-293B	12/21/82		0.662	0.598	0.587	0.612
399-294	01/03/83		4.232	0.416	2.160	0.350
399-295	01/03/83		0.271	0.329	0.414	0.292
400-296	01/04/83	1130	0.430	0.396	0.336	0.352
400-297A	01/04/83	1330	0.453	0.405	0.363	0.382
400-297B	01/04/83	1330	0.453	0.405	0.363	0.382
400-298A	01/04/83	1600	0.495	0.437	0.368	0.375
400-298B	01/04/83	1600	0.495	0.437	0.368	0.375
401-299	01/05/83		0.421	0.442	0.363	0.373
401-300A	01/05/83		0.499	0.442	0.370	0.375
401-300B	01/05/83		0.499	0.442	0.370	0.375
402-3011	01/06/83	1100	0.428	0.434	0.386	0.396
402-3012	01/06/83	1100	0.428	0.434	0.386	0.396
402-302	01/06/83	1300	0.446	0.421	0.400	0.393
402-3031	01/06/83	1500	0.474	0.430	0.426	0.389
402-3032	01/06/83	1500	0.474	0.430	0.426	0.389
406-304	01/10/83		0.377	0.340	0.317	0.294
407-305	01/11/83		0.442	0.352	0.354	0.315
407-3051	01/11/83		0.442	0.352	0.354	0.315
407-3052	01/11/83		0.442	0.352	0.354	0.315
408-306	01/12/83	1130	0.474	0.428	0.403	0.400
408-307	01/12/83	1600	0.508	0.465	0.423	0.428
409-308	01/13/83		1.175	0.835	0.713	0.626
409-309	01/13/83		1.132	0.906	0.662	0.685
413-310	01/17/83	1500	0.375	0.373	0.315	0.317
414-311	01/18/83	1100	0.621	0.559	0.529	0.506
414-312	01/18/83	1400	0.612	0.522	0.506	0.472
415-313	01/19/83	1200	0.720	0.626	0.580	0.529
415-314	01/19/83	1500	0.768	0.633	0.600	0.527
416-315	01/20/83	1200	0.911	0.777	0.651	0.621
416-316	01/20/83	1500	0.881	0.773	0.616	0.616
420-317	01/24/83	1300	0.405	0.338	0.338	0.285
420-318	01/24/83	1600	0.407	0.322	0.366	0.278

Table 2A. (Continued)

CODE	DATE	TIME	DIRECT UV TOTAL (CM-1)	DIRECT UV FILTER (CM-1)	SPHERE UV TOTAL (CM-1)	SPHERE UV FILTER (CM-1)
421-319	01/25/83	1100	0.639	0.538	0.465	0.490
421-320	01/25/83	1330	0.616	0.499	0.472	0.455
421-321	01/25/83	1500	0.550	0.474	0.416	0.423
422-322	01/26/83	1230	0.681	0.554	0.547	0.529
422-323	01/26/83	1630	0.639	0.541	0.495	0.499
423-324	01/27/83	1230	0.557	0.499	0.474	0.455
423-325	01/27/83	1530	0.621	0.504	0.485	0.449
427-326	01/31/83	1145	0.485	0.340	0.340	0.306
427-327	01/31/83	1330	0.435	0.345	0.345	0.297
427-328	01/31/83	1600	0.444	0.373	0.336	0.308
428-329	02/01/83	1130	0.589	0.430	0.426	0.337
428-330	02/01/83	1330	0.527	0.380	0.377	0.338
428-331	02/01/83	1700	0.543	0.428	0.393	0.366
429-332	02/02/83	1100	0.527	0.455	0.428	0.412
429-333	02/02/83	1500	0.518	0.407	0.386	0.361
430-334	02/03/83	1200	0.435	0.366	0.345	0.306
430-335	02/03/83	1430	0.490	0.398	0.400	0.343
441-336	02/09/83		0.495	0.366	0.294	0.458
444-337	02/17/83	1200	0.508	0.400	0.359	0.306
444-338	02/17/83		0.449	0.400	0.345	0.345
455-339	02/28/83		0.488	0.304	0.308	0.276
455-340	02/28/83		0.488	0.294	0.336	0.271
462-341	03/07/83	1100	0.504	0.373	0.345	0.304
462-342	03/07/83	1230	0.426	0.370	0.329	0.301
462-343	03/07/83	1430	0.451	0.368	0.345	0.306
463-344	03/08/83	1115	0.492	0.439	0.405	0.393
463-345	03/08/83	1230	0.497	0.419	0.405	0.377
463-346	03/08/83	CSO	*****	*****	*****	*****
464-347	03/09/83		0.545	0.426	0.405	0.380
464-348	03/09/83		0.559	0.426	0.430	0.375
464-349	03/09/83		0.358	0.420	0.416	0.382
469-350	03/14/83	1200	0.292	0.288	0.242	0.255
469-351	03/14/83	1400	0.373	0.366	0.278	0.290
470-352	03/15/83		0.419	0.370	0.375	0.327
470-353	03/15/83		0.416	0.409	0.370	0.361
471-354	03/16/83	1130	0.488	0.442	0.416	0.398
471-355	03/16/83	1430	0.462	0.428	0.419	0.389
472-356	03/17/83	1130	0.557	0.462	0.426	0.414
472-357	03/17/83	1500	0.573	0.485	0.451	0.428
476-358	03/21/83	CSO	*****	*****	*****	*****
476-359	03/21/83	CSO	*****	*****	*****	*****
477-360	03/22/83		0.366	0.375	0.352	0.343
477-361	03/22/83	1500	0.426	0.407	0.377	0.363
478-362	03/23/83	1430	0.460	0.412	0.377	0.375
479-363	03/24/83	1100	0.232	0.458	0.458	0.439
483-364	03/28/83	1130	0.485	0.242	0.398	0.278
483-365	03/28/83	1500	0.354	0.235	0.306	0.271

Table 2A. (Continued)

CODE	DATE	TIME	DIRECT UV TOTAL (CM-1)	UIRECT UV FILTER (CM-1)	SPHERE UV TOTAL (CM-1)	SPHERE UV FILTER (CM-1)
484-366	03/29/83	1130	0.449	U.357	0.419	0.393
484-367	03/29/83	1500	0.462	U.350	0.412	0.391
497-368	04/11/83		0.331	U.306	0.278	0.276
497-369	04/11/83		0.331	U.301	0.278	0.274
497-370	04/11/83		0.299	U.294	0.274	0.271
498-371	04/12/83	1030	0.363	U.329	0.298	0.299
498-372	04/12/83	1300	0.384	U.331	0.322	0.299
498-373	04/12/83	1600	0.317	U.304	0.283	0.276
499-374	04/13/83		0.403	U.340	0.322	0.322
499-375	04/13/83		0.389	U.373	0.350	0.336
499-376	04/13/83		0.366	U.373	0.345	0.329
500-377	04/14/83	0800	0.478	U.419	0.414	0.361
500-378	04/14/83	0925	0.400	U.370	0.361	0.345
500-379	04/14/83	1100	0.400	U.370	0.359	0.345
500-380	04/14/83	1415	0.352	U.386	0.345	0.343
500-381	04/14/83	1515	0.354	U.361	0.329	0.331
500-382	04/14/83	1600	0.375	U.377	0.345	0.352
504-383	04/18/83	1300	0.292	U.294	0.269	0.253
504-384	04/18/83	1500	0.288	U.271	0.253	0.254
504-385	04/18/83	1700	0.334	0.320	0.276	0.267
505-386	04/19/83	1200	0.336	0.336	0.297	0.294
505-387	04/19/83	1400	0.366	U.306	0.285	0.285
505-388	04/19/83	1600	0.405	U.329	0.317	0.285
506-389	04/20/83		0.331	U.301	0.283	0.267
506-390	04/20/83		0.301	U.299	0.283	0.265
506-391	04/20/83		0.313	U.352	0.315	0.308
507-392	04/21/83		0.377	U.357	0.334	0.315
507-393	04/21/83		0.331	0.347	0.320	0.313
507-394	04/21/83		0.345	0.354	0.317	0.292
507-395	04/21/83		0.347	0.340	0.320	0.301
507-396	04/21/83		0.322	U.345	0.308	0.311
507-397	04/21/83		0.375	U.359	0.336	0.327
511-398	04/25/83	1100	0.242	U.232	0.216	0.239
511-399	04/25/83	1200	0.265	U.258	0.228	0.232
511-400	04/25/83	1500	0.396	U.290	0.306	0.253
512-401	04/26/83	1230	0.313	U.281	0.276	0.267
512-402	04/26/83	1400	0.331	U.301	0.290	0.271
512-403	04/26/83	1530	0.258	U.278	0.246	0.262
513-404	04/27/83	1000	0.334	U.322	0.292	0.294
513-405	04/27/83	1130	0.331	U.327	0.327	0.290
513-406	04/27/83	1530	0.311	U.315	0.285	0.290
514-407	04/28/83	1100	0.313	U.322	0.281	0.285
514-408	04/28/83	1300	0.407	U.331	0.290	0.274
514-409	04/28/83	1500	0.313	U.315	0.292	0.285
520-410	05/04/83	1100	0.593	U.568	0.545	0.541
520-411	05/04/83	1300	0.651	U.577	0.547	0.543
520-412	05/04/83	1530	0.593	U.513	0.515	0.481

Table 2A. (Continued)

CODE	DATE	TIME	DIRECT UV TOTAL (CM-1)	DIRECT UV FILTER (CM-1)	SPHERE UV TOTAL (CM-1)	SPHERE UV FILTER (CM-1)
521-413	05/05/83	1200	0.573	0.426	0.444	0.389
521-414	05/05/83	1330	0.598	0.455	0.478	0.419
521-415	05/05/83	1500	0.672	0.460	0.520	0.421
574-416	06/27/83		0.288	0.294	0.255	0.271
574-417	06/27/83		0.299	0.283	0.260	0.253
574-418	06/27/83		0.297	0.301	0.260	0.269
575-419	06/28/83		0.451	0.439	0.405	0.409
575-420	06/28/83		0.446	0.437	0.409	0.414
575-421	06/28/83		0.492	0.485	0.453	0.458
576-422	06/29/83		0.492	0.515	0.430	0.444
576-423	06/29/83		0.458	0.469	0.405	0.416
576-424	06/29/83		0.483	0.506	0.435	0.460
577-425	06/30/83		0.403	0.400	0.361	0.368
577-426	06/30/83		0.398	0.368	0.370	0.389
577-427	06/30/83		0.391	0.407	0.366	0.373
589-428	07/12/83	1100	0.460	0.334	0.285	0.262
589-429	07/12/83	1300	0.420	0.352	0.274	0.260
589-430	07/12/83	1515	0.446	0.350	0.292	0.285
590-431	07/13/83	1100	0.462	0.334	0.308	0.265
590-432	07/13/83	1315	0.453	0.347	0.308	0.290
590-433	07/13/83	1530	0.455	0.347	0.297	0.283
591-434	07/14/83		0.499	0.405	0.322	0.306
591-435	07/14/83		0.490	0.389	0.320	0.297
591-436	07/14/83		0.508	0.398	0.327	0.301
595-437	07/18/83	1000	0.347	0.297	0.260	0.246
595-438	07/18/83	1215	0.359	0.281	0.242	0.235
595-439	07/18/83	1500	0.380	0.292	0.265	0.255
596-440	07/19/83	1030	0.803	0.738	0.676	0.628
596-441	07/19/83	1330	0.989	0.807	0.688	0.681
597-442	07/20/83	1100	0.978	0.938	0.754	0.738
602-443	07/25/83	1200	0.708	0.524	0.446	0.403
602-444	07/25/83	1530	0.833	0.547	0.488	0.407
603-445	07/26/83	1005	1.030	0.649	0.589	0.497
603-446	07/26/83	1300	1.010	0.672	0.628	0.547
603-447	07/26/83	1615	1.030	0.642	0.566	0.481
604-448	07/27/83	0845	0.948	0.552	0.541	0.437
604-449	07/27/83	1130	0.991	0.575	0.570	0.458
604-450	07/27/83		0.934	0.610	0.575	0.488
605-451	07/28/83		1.000	0.633	0.610	0.495
605-452	07/28/83		0.975	0.665	0.607	0.504
605-453	07/28/83		1.100	0.702	0.623	0.521
609-454	08/01/83	1000	0.396	0.350	0.373	0.340
609-455	08/01/83	1130	0.345	0.329	0.363	0.350
609-456	08/01/83	1400	0.336	0.315	0.398	0.345
610-457	08/02/83	0930	0.444	0.449	0.476	0.481
610-458	08/02/83	1115	0.409	0.407	0.435	0.435
610-459	08/02/83	1500	0.391	0.400	0.428	0.430

Table 2A. (Continued)

CODE	DATE	TIME	DIRECT UV TOTAL (CM-1)	DIRECT UV FILTER (CM-1)	SPHERE UV TOTAL (CM-1)	SPHERE UV FILTER (CM-1)
611-460	08/03/83	0930	0.451	0.524	0.478	0.524
611-461	08/03/83	1230	0.423	0.451	0.462	0.483
611-462	08/03/83	1500	0.423	0.435	0.467	0.465
612-463	08/04/83	0945	0.423	0.449	0.442	0.460
612-464	08/04/83	1330	0.469	0.524	0.510	0.529
612-465	08/04/83	1345	0.451	0.518	0.474	0.529
616-466	08/08/83	0935	0.347	0.340	0.297	0.294
616-467	08/08/83	1145	0.347	0.315	0.276	0.274
616-468	08/08/83	1500	0.368	0.317	0.290	0.281
617-469	08/09/83	0945	0.446	0.398	0.361	0.361
617-470	08/09/83	1200	0.396	0.368	0.354	0.338
617-471	08/09/83	1500	0.407	0.370	0.345	0.334
618-472	08/10/83	1000	0.393	0.352	0.336	0.327
618-473	08/10/83	1200	0.423	0.389	0.363	0.361
618-474	08/10/83	1400	0.557	0.513	0.488	0.485
619-475	08/11/83	0925	0.483	0.437	0.398	0.403
619-476	08/11/83	1130	0.506	0.451	0.432	0.423
619-477	08/11/83	1430	0.559	0.467	0.446	0.444
630-478	08/22/83	1000	0.336	0.283	0.258	0.239
630-479	08/22/83	1200	0.285	0.258	0.230	0.230
631-480	08/23/83	1000	0.478	0.414	0.451	0.391
631-481	08/23/83	1200	0.428	0.485	0.398	0.423
632-482	08/24/83		0.460	0.393	0.405	0.361
632-483	08/24/83		0.382	0.391	0.354	0.354
633-484	08/25/83	1000	0.623	0.497	0.534	0.451
633-485	08/25/83	1330	0.587	0.575	0.662	0.513

Table 2A. (Continued)

CODE	DATE	TIME	COD TOTAL (MG/L)	COD FILTER (MG/L)	TOC TOTAL (MG/L)	TOC FILTER (MG/L)	TKN TOTAL (MG/L)	TKN FILTER (MG/L)	NH3-N (MG/L)	NO2-N (MG/L)	NO3-N (MG/L)
002-001	12/02/81	0930	48.0	48.0	16.5	16.8	******	******	******	******	******
002-002	12/02/81	1045	48.0	29.0	16.0	15.0	******	******	******	******	******
002-003	12/02/81	1200	38.0	38.0	16.0	6.0	******	******	******	******	******
002-004	12/02/81	1430	49.0	48.0	16.0	15.0	******	******	******	******	******
003-005	12/03/81	0830	84.0	68.0	21.5	18.5	4.30	3.80	1.80	0.080	0.090
003-006	12/03/81	1045	80.0	80.0	19.5	17.5	5.30	4.00	1.70	0.080	1.100
003-007	12/03/81	1130	76.0	72.0	19.0	19.0	8.00	5.50	1.70	0.070	1.200
003-008	12/03/81	1300	52.0	52.0	22.0	19.0	6.00	4.00	2.70	0.080	1.100
007-009	12/07/81	0930	36.0	36.0	18.0	16.0	4.50	4.30	2.00	0.400	6.100
007-010	12/07/81	1350	40.0	40.0	17.0	17.0	4.00	3.00	2.90	0.400	5.500
007-011	12/07/81		36.0	32.0	13.0	17.0	5.00	4.80	3.50	0.400	5.600
014-012	12/14/81	0800	80.0	44.0	14.0	12.0	******	******	******	******	******
014-013	12/14/81	1130	64.0	48.0	13.0	9.0	******	******	******	******	******
014-014	12/14/81	1415	72.0	40.0	13.0	12.0	******	******	******	******	******
015-015	12/15/81	1030	32.0	20.0	9.5	5.5	******	******	******	******	******
015-016	12/15/81	1200	64.0	48.0	10.5	9.0	******	******	******	******	******
015-017	12/15/81	1330	56.0	36.0	10.5	10.5	******	******	******	******	******
016-018	12/16/91	1115	24.0	20.0	11.5	9.0	******	******	******	******	******
016-019	12/16/81	1230	36.0	16.0	12.0	10.0	******	******	******	******	******
017-020	12/17/81	0830	36.0	28.0	16.0	13.0	******	******	******	******	******
017-021	12/17/81	1115	32.0	32.0	18.5	14.0	******	******	******	******	******
017-022	12/17/81	1415	24.0	16.0	20.5	15.0	******	******	******	******	******
021-023	12/21/81	0930	36.0	24.0	35.5	25.5	******	******	******	******	******
021-024	12/21/81	1130	56.0	28.0	27.5	16.5	******	******	******	******	******
021-025	12/21/81	1345	68.0	28.0	28.0	15.0	******	******	******	******	******
023-026	12/23/81	1000	76.0	40.0	21.0	14.5	******	******	******	******	******
023-027	12/23/81	1130	44.0	20.0	32.0	12.5	******	******	******	******	******
023-028	12/23/81	1330	52.0	40.0	15.0	15.0	******	******	******	******	******
028-029	12/28/81	0830	48.0	36.0	10.5	17.0	******	******	******	******	******
028-030	12/28/81	1000	47.0	35.0	13.0	13.5	******	******	******	******	******
028-031	12/28/81	1230	47.0	23.0	7.0	13.5	******	******	******	******	******
029-032	12/29/81	0900	35.0	31.0	14.0	19.0	******	******	******	******	******
029-033	12/29/81	1130	35.0	31.0	13.5	18.0	******	******	******	******	******
029-034	12/29/81	1330	35.0	24.0	14.0	17.5	******	******	******	******	******
035-035	01/04/82	1000	27.0	16.0	9.5	10.0	4.30	4.00	1.60	0.150	0.800
035-036	01/04/82		24.0	16.0	8.0	8.5	4.00	4.10	1.70	0.070	0.800
035-037	01/04/82		16.0	16.0	10.0	10.3	4.30	4.00	2.20	0.090	0.900
035-038	01/04/82		24.0	16.0	9.5	11.5	4.00	3.50	1.90	0.050	1.000
037-039	01/06/82	0700	31.0	31.0	16.5	16.5	******	******	******	******	******
037-040	01/06/82	0930	40.0	55.0	14.0	16.5	******	******	******	******	******
037-041	01/06/82	1200	28.0	40.0	14.0	16.0	******	******	******	******	******
038-042	01/07/82	0700	44.0	40.0	24.0	23.0	******	******	******	******	******
038-043	01/07/82	1200	48.0	44.0	22.0	23.5	******	******	******	******	******
041-044	01/11/82	1330	76.0	76.0	20.5	19.0	******	******	******	******	******
042-045	01/12/82	0945	84.0	71.0	21.0	18.0	13.50	8.00	3.90	******	7.000
042-046	01/12/82	1115	75.0	71.0	21.0	18.0	13.00	6.30	3.80	******	6.900
042-047	01/12/82	1400	71.0	71.0	43.5	16.0	16.00	3.70	4.00	******	4.300
051-048	01/20/82	1015	70.0	55.0	33.5	31.0	10.40	9.20	9.40	******	0.290

Table 2B. Influent (Secondary) to UV Units - Water Quality

CODE	DATE	TIME	COD TOTAL (MG/L)	COD FILTER (MG/L)	TOC TOTAL (MG/L)	TOC FILTER (MG/L)	TKN TOTAL (MG/L)	TKN FILTER (MG/L)	NH3-N (MG/L)	NO2-N (MG/L)	NO3-N (MG/L)
051-049	01/20/82	1145	70.0	55.0	33.0	29.0	13.60	8.60	10.40	******	0.020
051-050	01/20/82	1315	78.0	55.0	33.5	28.5	9.20	8.70	9.40	******	0.020
058-051	01/27/82	0945	******	30.0	28.0	24.5	6.10	5.70	4.30	******	******
058-052	01/27/82	1145	******	******	26.0	23.0	6.30	5.70	6.70	******	******
058-053	01/27/82	1315	******	30.0	26.0	23.0	6.20	6.30	6.30	******	******
059-054	01/28/82	1000	56.4	37.6	25.5	26.0	******	******	******	******	******
059-055	01/28/82	1145	48.9	41.4	30.5	27.0	******	******	******	******	******
059-056	01/28/82	1330	49.9	30.0	35.5	31.0	******	******	******	******	******
066-057	02/04/82	1000	52.0	48.0	15.0	21.0	******	******	******	******	******
066-058	02/04/82	1330	36.0	32.0	17.5	19.5	******	******	******	******	******
071-059	02/09/82	1115	44.0	32.0	22.5	22.0	******	******	******	******	******
071-060	02/09/82	1400	24.0	******	24.0	19.5	******	******	******	******	******
072-061	02/10/82	0930	28.0	28.0	26.0	20.5	******	******	******	******	******
072-062	02/10/82	1130	31.0	21.0	26.5	23.5	******	******	******	******	******
072-063	02/10/82	1430	49.0	45.0	43.5	35.5	******	******	******	******	******
073-064	02/11/82	1030	28.0	28.0	27.0	25.0	******	******	******	******	******
073-065	02/11/82	1230	35.0	28.0	30.0	25.0	******	******	******	******	******
073-066	02/11/82	1430	70.0	24.0	35.5	28.5	******	******	******	******	******
078-067	02/16/82	1100	28.0	21.0	29.5	19.0	******	******	******	******	******
078-068	02/16/82	1330	49.0	14.0	23.0	18.0	******	******	******	******	******
079-069	02/17/82	1000	90.0	42.0	******	32.5	******	******	******	******	******
079-070	02/17/82	1145	87.0	35.0	******	37.0	******	******	******	******	******
079-071	02/17/82	1400	77.0	38.0	******	******	******	******	******	******	******
086-072	02/24/82	1000	44.0	44.0	31.5	34.5	9.70	9.70	9.10	0.040	0.050
086-073	02/24/82		44.0	33.0	36.0	29.0	13.10	6.30	9.20	0.060	0.100
087-074	02/25/82	1000	36.0	29.0	34.0	31.0	******	******	******	******	******
087-075	02/25/82	1400	29.0	22.0	35.0	30.0	******	******	******	******	******
091-076	03/01/82	1030	25.0	25.0	11.0	6.0	******	******	******	******	******
091-077	03/01/82	1230	61.0	22.0	7.0	5.0	******	******	******	******	******
091-078	03/01/82	1400	32.0	22.0	6.0	5.0	******	******	******	******	******
092-079	03/02/82	1000	47.0	40.0	7.0	5.0	******	******	******	******	******
092-080	03/02/82	1200	50.0	32.0	8.0	9.0	******	******	******	******	******
092-081	03/02/82	1400	31.0	15.0	11.0	8.0	******	******	******	******	******
093-082	03/03/82	1030	35.0	23.0	8.0	6.0	******	******	******	******	******
093-083	03/03/82	1230	23.0	19.0	8.0	5.0	******	******	******	******	******
093-084	03/03/82		35.0	27.0	4.0	5.0	******	******	******	******	******
094-085	03/04/82	1030	19.0	15.0	7.0	4.0	******	******	******	******	******
094-086	03/04/82	1230	36.0	25.0	5.0	3.0	******	******	******	******	******
094-087	03/04/82	1400	73.0	29.0	8.0	5.0	******	******	******	******	******
098-088	03/08/82	1115	36.0	29.0	3.0	******	******	******	******	******	******
098-089	03/08/82	1230	36.0	33.0	10.0	4.0	******	******	******	******	******
098-090	03/08/82	1430	33.0	29.0	5.0	3.0	******	******	******	******	******
099-091	03/09/82	1000	48.0	33.0	15.0	6.0	******	******	******	******	******
099-092	03/09/82	1200	48.0	33.0	8.0	6.0	******	******	******	******	******
099-093	03/09/82	1430	63.0	48.0	9.0	8.0	******	******	******	******	******
100-094	03/10/82	1115	44.0	29.0	7.0	6.0	******	******	******	******	******
100-095	03/10/82	1400	44.0	29.0	8.0	8.0	******	******	******	******	******
105-096	03/15/82	0915	48.0	33.0	10.0	9.0	******	******	******	******	******

Table 2B. (Continued)

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*   CODE   * *   DATE   * *TIME* * COD    * * COD    * * TOC    * * TOC    * * TKN    * * TKN    * *NH3-N   * *NO2-N   * *NO3-N   *
*          * *          * *    * *TOTAL   * *FILTER* *TOTAL   * *FILTER* *TOTAL   * *FILTER* *        * *        * *        *
*          * *          * *    * *(MG/L)* *(MG/L)* *(MG/L)* *(MG/L)* *(MG/L)* *(MG/L)* *(MG/L)* *(MG/L)* *(MG/L)*

  105-097     03/15/82              45.0       45.0        9.0        9.0    ******     ******     ******     ******     ******
  106-098     03/16/82    0930      56.0       45.0       27.0       14.0     13.00      10.00       9.90      0.050      0.050
  106-099     03/16/82    1200      52.0       37.0       15.0       12.0     12.00      11.00       9.80     ******      0.050
  106-100     03/16/82    1400      57.0       41.0        9.0        9.0     12.00      10.00       9.80     ******      0.100
  107-101     03/17/82    1130      36.0       32.0       10.0       10.0    ******     ******     ******     ******     ******
  107-102     03/17/82    1430      43.0       29.0       10.0        9.0    ******     ******     ******     ******     ******
  149-103     04/28/82    1015      53.0       35.0       15.5       10.0      6.40       0.71       0.04      0.110      0.210
  149-104     04/28/82    1130      62.0       32.0       14.0       13.0      9.80       1.90       1.30      0.130      0.020
  149-105     04/28/82    1330      58.0       33.0       18.0       15.0     11.10       0.37       0.20      1.670      8.200
  150-106     04/29/82    1015      57.0       48.0       16.0       14.0    ******     ******     ******     ******     ******
  154-107     05/03/82    1200      72.0       40.0       18.0       16.0    ******     ******     ******     ******     ******
  154-108     05/03/82    1415      67.0       34.0       17.0       14.0    ******     ******     ******     ******     ******
  155-109     05/04/82    0930      82.0       53.0       18.0       17.5    ******     ******     ******     ******     ******
  155-110     05/04/82    1200      76.0       50.0       19.0       16.5    ******     ******     ******     ******     ******
  155-111     05/04/82    1430      69.0       49.0       18.0       16.0    ******     ******     ******     ******     ******
  156-112     05/05/82              75.0       51.0       19.0       19.0    ******     ******     ******     ******     ******
  156-113     05/05/82              66.0       61.0       17.5       17.0    ******     ******     ******     ******     ******
  157-114     05/06/82    0930      72.0       42.0       17.5       16.0     11.30       9.90       6.40     ******     ******
  157-115     05/06/82    1100      68.0       44.0       18.5       15.0     12.00       7.40       9.40     ******     ******
  157-116     05/06/82    1330      40.0       48.0       19.0       17.0     13.20       8.20       6.70     ******     ******
  161-117     05/10/82    1230      14.0     ******       14.0       14.0    ******     ******     ******     ******     ******
  161-118     05/10/82    1430      20.0     ******       18.0       13.0    ******     ******     ******     ******     ******
  162-119     05/11/82              18.0       14.0       16.5       15.0    ******     ******     ******     ******     ******
  168-120     05/17/82            ******     ******     ******     ******    ******     ******     ******     ******     ******
  169-121     05/18/82    1100    ******     ******       11.0        6.0    ******     ******     ******     ******     ******
  169-122     05/18/82    1330    ******     ******        9.0        1.0    ******     ******     ******     ******     ******
  171-123     05/20/82    1030    ******     ******        9.0        4.0    ******     ******     ******     ******     ******
  176-124     05/25/82    1000      24.0       21.0       13.5       12.0      7.60       7.40       6.60      0.080      0.190
  176-125     05/25/82    1230      32.0       23.0       13.0       12.5      9.00       8.40       7.30      0.060      0.180
  176-126     05/25/82    1500      30.0       27.0       13.5       13.0      9.60       8.40       7.90      0.050      0.120
  177-127     05/26/82    1000      44.0       42.0       13.5       12.0    ******     ******     ******     ******     ******
  177-128     05/26/82    1200      44.0       44.0       13.0       11.0    ******     ******     ******     ******     ******
  177-129     05/26/82    1500      43.0       44.0       15.0       11.0    ******     ******     ******     ******     ******
  183-130     06/01/82    1000      40.0       33.0       14.5       11.5    ******     ******     ******     ******     ******
  183-131     06/01/82    1230      44.0       31.0       14.5       11.0    ******     ******     ******     ******     ******
  183-132     06/01/82    1450      40.0       30.0       13.5       11.0    ******     ******     ******     ******     ******
  196-133     06/14/82              30.0       25.0        6.5        6.5      1.89       1.67     ******     ******      6.500
  196-134     06/14/82              36.0       28.0        6.0        6.0      1.74       0.87     ******     ******      7.300
  196-135     06/14/82              29.0       26.0        7.0        6.5      1.38       1.31     ******     ******      9.600
  197-136     06/15/82    1130      34.0       33.0        7.0        7.0    ******     ******     ******     ******     ******
  197-137     06/15/82    1430      31.0       27.0        8.0        8.0    ******     ******     ******     ******     ******
  197-138     06/15/82    1600      34.0       27.0        9.0        7.0    ******     ******     ******     ******     ******
  198-139     06/16/82    1200      34.0       31.0        9.0        7.5    ******     ******     ******     ******     ******
  198-140     06/16/82    1400      35.0       26.0        8.5        7.0    ******     ******     ******     ******     ******
  198-141     06/16/82    1615      36.0       28.0        8.5        8.0    ******     ******     ******     ******     ******
  203-142     06/21/82    1130      39.0       30.0       12.0        9.0      6.00      12.90       5.77     ******      3.000
  203-143     06/21/82    1330      44.0       29.0       11.0        6.5      6.60      11.00       6.00     ******      3.300
  203-144     06/21/82    1530      43.0       31.0       11.5        7.5      7.50       8.70       7.17     ******      3.000
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Table 2B. (Continued)

CODE	DATE	TIME	COD TOTAL (MG/L)	COD FILTER (MG/L)	TOC TOTAL (MG/L)	TOC FILTER (MG/L)	TKN TOTAL (MG/L)	TKN FILTER (MG/L)	NH3-N (MG/L)	NO2-N (MG/L)	NO3-N (MG/L)
204-145	06/22/82	1030	40.0	31.0	11.0	8.5	******	******	******	******	******
204-146	06/22/82	1315	41.0	32.0	10.5	8.5	******	******	******	******	******
204-147	06/22/82	1600	34.0	31.0	10.0	8.0	******	******	******	******	******
205-148	06/23/82	1015	35.0	34.0	9.0	9.0	******	******	******	******	******
205-149	06/23/82	1230	34.0	34.0	10.0	10.0	******	******	******	******	******
205-150	06/23/82	1500	36.0	31.0	11.0	10.5	******	******	******	******	******
210-151	06/28/82	0930	30.0	24.0	10.0	8.5	3.80	3.80	1.68	0.670	5.700
210-152	06/28/82	1100	******	******	10.0	7.0	4.30	3.90	1.65	0.820	5.700
210-153	06/28/82	1330	******	******	10.0	7.0	4.20	5.60	1.79	0.680	5.300
211-154	06/29/82	0815	25.0	23.0	10.5	10.5	******	******	******	******	******
211-155	06/29/82	1115	28.0	21.0	10.0	9.0	******	******	******	******	******
211-156	06/29/82	1330	27.0	21.0	9.0	9.5	******	******	******	******	******
212-157	06/30/82	0830	30.0	26.0	9.0	9.0	******	******	******	******	******
212-158	06/30/82	1100	26.0	26.0	10.0	9.5	******	******	******	******	******
212-159	06/30/82	1330	33.0	******	10.5	10.5	******	******	******	******	******
218-160	07/06/82	0900	31.0	29.0	10.0	9.5	0.74	2.86	3.58	0.580	3.100
218-161	07/06/82	1115	29.0	27.0	8.5	8.5	0.92	2.36	2.04	0.490	4.400
218-162	07/06/82	1330	29.0	26.0	8.5	8.5	1.30	2.48	2.64	0.720	5.300
219-163	07/07/82	1200	26.0	24.0	8.5	7.0	******	******	******	******	******
225-164	07/13/82	0900	42.0	40.0	14.0	15.0	1.36	3.17	2.87	0.440	2.700
225-165	07/13/82	1115	44.0	39.0	12.5	13.5	0.92	2.60	3.40	******	0.550
225-166	07/13/82	1400	41.0	39.0	12.5	13.5	1.98	2.55	2.64	0.540	3.500
226-167	07/14/82	0900	40.0	40.0	11.0	11.5	******	******	******	******	******
226-168	07/14/82	1130	40.0	37.0	7.5	13.0	******	******	******	******	******
226-169	07/14/82	1400	44.0	41.0	10.0	8.0	******	******	******	******	******
231-170	07/19/82	0930	22.0	30.0	7.0	9.0	1.67	1.67	0.93	0.310	5.800
231-171	07/19/82	1200	25.0	23.0	6.0	7.0	1.11	2.17	1.29	0.250	6.300
231-172	07/19/82	1430	20.0	25.0	6.0	6.0	2.61	3.04	1.63	0.340	6.500
239-173	07/27/82	0900	24.0	23.0	9.0	9.0	2.94	2.67	1.55	0.100	1.200
239-174	07/27/82	1130	24.0	22.0	9.0	9.0	1.88	2.07	1.11	0.070	1.180
239-175	07/27/82	1400	30.0	25.0	9.0	10.0	2.94	2.94	1.55	0.060	0.810
240-176	07/28/82	0830	29.0	29.0	9.0	10.0	******	******	******	******	******
240-177	07/28/82	1100	30.0	28.0	9.0	10.0	******	******	******	******	******
240-178	07/28/82	1400	32.0	27.0	10.0	10.5	******	******	******	******	******
241-179	07/29/82	0830	23.0	22.0	11.0	9.0	******	******	******	******	******
245-180	08/02/82	0900	23.0	24.0	6.0	7.0	0.90	0.87	0.82	0.470	5.900
245-181	08/02/82	1100	23.0	22.0	6.0	6.0	1.10	1.06	0.74	0.390	6.800
245-182	08/02/82	1330	21.0	20.0	6.0	6.5	0.84	0.81	1.40	0.640	8.000
246-183	08/03/82	0900	26.0	24.0	6.5	7.0	******	******	******	******	******
246-184	08/03/82	1115	30.0	28.0	7.0	7.0	******	******	******	******	******
246-185	08/03/82	1330	32.0	33.0	8.0	7.5	******	******	******	******	******
247-186	08/04/82	0900	34.0	32.0	8.5	8.5	******	******	******	******	******
247-187	08/04/82	1130	31.0	31.0	7.0	7.5	******	******	******	******	******
247-188	08/04/82	1400	30.0	31.0	8.5	8.0	******	******	******	******	******
252-189	08/09/82	0900	43.0	29.0	7.5	7.0	0.78	0.71	0.38	******	7.300
252-190	08/09/82	1130	36.0	35.0	9.0	7.5	0.84	0.97	0.36	******	7.800
252-191	08/09/82	1430	32.0	33.0	7.0	7.0	1.04	0.84	0.15	0.020	8.400
253-192	08/10/82	0900	47.0	29.0	11.0	10.0	******	******	******	******	******

Table 2B. (Continued)

CODE	DATE	TIME	COD TOTAL (MG/L)	COD FILTER (MG/L)	TOC TOTAL (MG/L)	TOC FILTER (MG/L)	TKN TOTAL (MG/L)	TKN FILTER (MG/L)	NH3-N (MG/L)	NO2-N (MG/L)	NO3-N (MG/L)
253-193	08/10/82		45.0	32.0	9.0	9.0	******	******	******	******	******
253-194	08/10/82	1330	47.0	37.0	9.0	9.0	******	******	******	******	******
254-195	08/11/82	1015	35.0	34.0	9.5	9.0	******	******	******	******	******
254-196	08/11/82	1200	42.0	34.0	9.0	8.5	******	******	******	******	******
254-197	08/11/82	1400	32.0	32.0	9.0	8.5	******	******	******	******	******
260-198	08/17/82	1150	35.0	25.0	15.0	6.0	******	******	******	******	******
260-199	08/17/82	1300	48.0	32.0	6.0	6.0	******	******	******	******	******
266-200	08/23/82	0940	23.0	23.0	9.0	11.0	******	******	******	******	******
266-201	08/23/62	1135	22.0	21.0	10.0	10.0	******	******	******	******	******
266-202	08/23/82	1345	20.0	15.0	11.0	9.0	******	******	******	******	******
267-203	08/24/82	0930	27.0	34.7	12.0	13.0	******	******	******	******	******
267-204	08/24/82	1145	34.7	33.0	26.0	13.0	******	******	******	******	******
267-205	08/24/82	1410	34.7	29.8	12.0	12.0	******	******	******	******	******
268-206	08/25/82	0920	33.2	22.3	16.0	14.0	******	******	******	******	******
268-207	08/25/82	1145	62.0	22.3	20.0	23.0	******	******	******	******	******
268-208	08/25/82	1420	17.3	28.2	11.0	13.0	******	******	******	******	******
274-209	08/31/82		33.2	33.2	12.0	12.0	******	******	******	******	******
275-210	09/01/82	0900	62.7	28.0	14.0	16.0	0.75	1.21	0.38	0.100	2.600
275-211	09/01/82	1100	28.0	28.0	14.0	12.0	1.01	0.88	0.30	0.100	2.800
275-212	09/01/82	1400	35.4	30.5	13.0	12.0	1.21	0.22	0.12	0.300	3.900
281-213	09/07/82	1200	22.1	14.7	7.0	12.0	0.08	1.94	0.24	0.500	7.100
281-214	09/07/82	1330	22.1	14.7	6.0	8.0	0.61	0.48	0.35	0.500	7.100
282-215	09/08/82	1130	36.9	******	7.0	10.0	******	******	******	******	******
282-216	09/08/82		41.8	39.3	11.0	8.0	******	******	******	******	******
282-217	09/08/82		******	******	******	******	******	******	******	******	******
296-218	09/22/82	1200	25.0	31.0	17.0	16.0	******	******	******	******	******
308-219	10/04/82	1330	36.0	32.0	16.0	12.0	2.04	9.76	7.70	0.020	4.300
308-220	10/04/82	1600	44.0	31.0	19.0	12.0	3.70	9.42	8.60	0.020	4.600
309-221	10/05/82		42.0	35.0	16.0	25.0	******	******	******	******	******
309-222	10/05/82		44.0	24.0	13.0	21.0	******	******	******	******	******
310-223	10/06/82	1100	26.0	30.0	20.0	19.0	******	******	******	******	******
310-224	10/06/82	1400	29.0	23.0	19.0	20.0	******	******	******	******	******
315-225	10/12/82	1130	32.0	24.0	14.0	16.0	1.22	1.78	1.20	0.050	7.200
315-226	10/12/82	1515	27.0	32.0	******	14.0	2.94	3.56	2.50	0.770	7.000
316-227	10/13/82	CSO	******	******	******	******	******	******	******	******	******
321-228	10/18/82	1200	32.0	22.0	24.0	16.0	6.52	7.49	5.90	2.200	5.400
321-229	10/18/82	1400	39.0	29.0	16.0	16.0	8.11	7.97	6.70	2.200	5.000
321-230	10/18/82	1600	36.0	29.0	14.0	19.0	9.00	9.97	8.00	2.000	4.800
322-231	10/19/82		41.0	34.0	15.0	21.0	******	******	******	******	******
322-232	10/19/82		34.0	33.0	20.0	13.0	******	******	******	******	******
322-233	10/19/82		33.0	49.0	23.0	20.0	******	******	******	******	******
329-234	10/25/82	CSO	******	******	******	******	******	******	******	******	******
329-235	10/25/82	CSO	******	******	******	******	******	******	******	******	******
329-236	10/25/82	CSO	******	******	******	******	******	******	******	******	******
330-237	10/26/82		25.0	20.0	10.0	9.0	******	******	******	******	******
331-238	10/27/82	1130	42.0	32.0	21.0	17.0	******	******	******	******	******
331-239	10/27/82	1330	60.0	32.0	16.0	14.0	******	******	******	******	******
337-240	11/02/82	1100	79.0	51.0	10.0	9.0	******	******	******	******	******

Table 2B. (Continued)

CODE	DATE	TIME	COD TOTAL (MG/L)	COD FILTER (MG/L)	TOC TOTAL (MG/L)	TOC FILTER (MG/L)	TKN TOTAL (MG/L)	TKN FILTER (MG/L)	NH3-N (MG/L)	NO2-N (MG/L)	NO3-N (MG/L)
337-241	11/02/82	1300	79.0	79.0	8.0	10.0	******	******	******	******	******
337-242	11/02/82	1500	88.0	50.0	11.0	12.0	******	******	******	******	******
338-243	11/03/82	1030	105.0	46.0	11.0	10.0	******	******	******	******	******
338-244	11/03/82	1300	103.0	76.0	13.0	14.0	******	******	******	******	******
338-245	11/03/82	1500	109.0	33.7	******	15.0	******	******	******	******	******
343-246	11/08/82		41.6	33.7	11.0	14.0	7.78	9.10	7.16	1.200	3.400
343-247	11/08/82		31.7	37.7	10.0	22.0	10.70	9.48	8.55	1.200	3.300
345-248	11/10/82	1100	55.6	41.7	17.0	25.0	******	******	******	******	******
345-249	11/10/82		33.7	43.7	16.0	26.0	******	******	******	******	******
350-250	11/15/82	1130	46.0	53.0	20.0	25.0	0.50	0.62	0.13	******	10.700
350-251	11/15/82	1415	42.0	48.0	21.0	23.0	0.75	0.62	0.09	******	13.300
351-252	11/16/82	1100	44.0	46.0	24.0	30.0	******	******	******	******	******
351-253	11/16/82	1445	74.0	48.0	21.0	30.0	******	******	******	******	******
352-254	11/17/82	1130	45.0	26.0	22.0	27.0	******	******	******	******	******
352-255	11/17/82	1430	26.0	16.0	18.0	24.0	******	******	******	******	******
353-256	11/18/82	1200	22.0	14.0	20.0	26.0	******	******	******	******	******
353-257	11/18/82		45.0	16.0	21.0	27.0	******	******	******	******	******
357-258	11/22/82	1100	******	12.0	26.0	26.0	0.75	0.62	******	******	11.400
357-259	11/22/82	1430	22.0	25.0	23.0	25.0	0.81	0.75	******	******	14.200
357-259A	11/22/82	1430	******	******	******	******	******	******	******	******	******
358-260	11/23/82	1130	31.7	17.0	31.0	38.8	******	******	******	******	******
358-261	11/23/82	1430	23.0	23.0	28.3	36.8	******	******	******	******	******
358-261A	11/23/82	1430	******	******	******	******	******	******	******	******	******
364-262	11/29/82		40.0	26.0	13.1	20.3	******	******	******	******	******
364-263	11/29/82	1300	14.0	17.0	15.7	22.2	******	******	******	******	******
364-264	11/29/82	1500	29.0	******	19.5	22.2	******	******	******	******	******
365-265	11/30/82	1330	32.0	22.0	22.3	31.3	******	******	******	******	******
366-266	12/01/82	1230	51.0	38.0	32.0	33.5	******	******	******	******	******
367-267	12/02/82	1200	70.0	25.0	28.0	32.3	6.20	6.40	5.00	0.200	0.210
367-268	12/02/82	1415	41.0	25.0	35.6	37.6	8.20	9.20	8.00	0.170	0.240
367-269	12/02/82	1530	25.0	12.0	33.0	37.5	9.80	8.70	8.60	0.170	0.240
371-270	12/06/82	1230	22.0	******	33.6	35.8	11.00	6.40	11.00	0.840	0.320
371-271	12/06/82	1415	17.0	19.0	34.8	34.5	13.00	******	******	******	******
371-272	12/06/82	1600	21.0	******	34.1	33.1	1.50	5.80	12.00	1.600	0.570
372-273	12/07/82	1200	47.0	13.0	36.1	35.9	******	******	******	******	******
372-274	12/07/82	1415	15.0	31.0	37.3	36.7	******	******	******	******	******
372-275	12/07/82		******	******	******	******	******	******	******	******	******
373-276	12/08/82	1130	35.0	27.0	37.7	37.1	******	******	******	******	******
373-277	12/08/82		35.0	35.0	38.1	37.4	******	******	******	******	******
373-278	12/08/82		31.0	27.0	36.7	37.0	******	******	******	******	******
378-279	12/13/82	1200	******	******	30.3	30.1	******	******	******	******	******
378-280	12/13/82		40.0	******	29.1	30.1	******	******	******	******	******
378-281	12/13/82		17.0	17.0	31.2	30.6	******	******	******	******	******
379-282	12/14/82	1130	94.0	42.0	29.8	30.2	******	******	******	******	******
379-283	12/14/02		42.0	42.0	30.1	24.9	******	******	******	******	******
379-284	12/14/02		52.0	54.0	31.0	30.7	******	******	******	******	******
380-285	12/15/82	1500	40.0	40.0	40.0	40.3	******	******	******	******	******
381-286	12/16/02	CSO	******	******	******	******	******	******	******	******	******

Table 2B. (Continued)

CODE	DATE	TIME	COD TOTAL (MG/L)	COD FILTER (MG/L)	TOC TOTAL (MG/L)	TOC FILTER (MG/L)	TKN TOTAL (MG/L)	TKN FILTER (MG/L)	NH3-N (MG/L)	NO2-N (MG/L)	NO3-N (MG/L)
381-287	12/16/02	CSO	******	******	******	******	******	******	******	******	******
385-288	12/20/82		100.0	64.0	29.6	30.3	8.50	7.50	6.80	0.110	******
385-289	12/20/82		108.0	25.0	30.5	28.5	8.50	8.20	7.30	0.100	******
385-290	12/20/82		77.0	29.0	38.3	30.1	11.00	9.80	9.30	0.120	******
385-291	12/20/82		62.0	19.0	47.2	29.9	11.00	10.00	9.50	0.130	******
386-292A	12/21/82		83.0	29.0	33.2	32.1	******	******	******	******	******
386-292B	12/21/82		83.0	29.0	33.2	32.1	******	******	******	******	******
386-293A	12/21/82		75.0	50.0	41.3	38.8	******	******	******	******	******
386-293B	12/21/82		75.0	50.0	41.3	38.8	******	******	******	******	******
399-294	01/03/83		67.0	27.0	50.0	35.2	47.00	15.00	16.00	******	******
399-295	01/03/83		123.0	25.0	32.8	31.3	17.00	14.00	15.00	0.020	0.110
400-296	01/04/83	1130	32.0	28.0	31.6	31.1	******	******	******	******	******
400-297A	01/04/83	1330	35.0	25.0	32.6	32.3	******	******	******	******	******
400-297B	01/04/83	1330	35.0	25.0	32.6	32.3	******	******	******	******	******
400-298A	01/04/83	1600	37.0	29.0	34.7	34.3	******	******	******	******	******
400-298B	01/04/83	1600	37.0	29.0	34.7	34.3	******	******	******	******	******
401-299	01/05/83		40.0	31.0	37.5	35.0	******	******	******	******	******
401-300A	01/05/83		36.0	30.0	36.2	34.8	******	******	******	******	******
401-300B	01/05/83		36.0	30.0	36.2	34.8	******	******	******	******	******
402-3011	01/06/83	1100	44.0	26.0	23.9	25.5	******	******	******	******	******
402-3012	01/06/83	1100	44.0	26.0	23.9	25.5	******	******	******	******	******
402-302	01/06/83	1300	34.0	25.0	24.2	24.6	******	******	******	******	******
402-3031	01/06/83	1500	42.0	28.0	26.7	26.3	******	******	******	******	******
402-3032	01/06/83	1500	42.0	28.0	26.7	26.3	******	******	******	******	******
406-304	01/10/83		42.0	41.0	30.8	30.5	13.00	12.00	11.00	******	0.160
407-305	01/11/83		32.0	24.0	26.4	26.7	6.70	6.90	6.00	******	0.230
407-3051	01/11/83		32.0	24.0	26.4	25.7	7.00	6.90	6.00	******	0.230
407-3052	01/11/83		32.0	24.0	26.4	25.7	7.00	6.90	6.00	******	0.230
408-306	01/12/83	1130	40.0	24.0	31.9	31.4	******	******	******	******	******
408-307	01/12/83	1600	37.0	23.0	33.8	33.3	******	******	******	******	******
409-308	01/13/83		106.0	77.0	51.3	49.2	******	******	******	******	******
409-309	01/13/83		77.0	77.0	48.6	48.3	******	******	******	******	******
413-310	01/17/83	1500	35.0	32.0	17.0	14.0	******	******	******	******	******
414-311	01/18/83	1100	49.0	37.0	14.0	******	******	******	******	******	******
414-312	01/18/83	1400	52.0	31.0	30.0	******	******	******	******	******	******
415-313	01/19/83	1200	61.0	45.0	16.0	******	******	******	******	******	******
415-314	01/19/83	1500	71.0	51.0	18.0	15.0	******	******	******	******	******
416-315	01/20/83	1200	100.0	66.0	23.0	20.0	******	******	******	******	******
416-316	01/20/83	1500	71.0	68.0	29.0	24.0	******	******	******	******	******
420-317	01/24/83	1300	46.0	27.0	63.0	51.0	12.00	8.50	8.00	0.110	0.630
420-318	01/24/83	1600	43.0	26.0	******	16.0	12.00	9.00	8.30	0.200	0.520
421-319	01/25/83	1100	62.0	39.0	24.0	12.0	******	******	******	******	******
421-320	01/25/83	1330	58.0	44.0	20.0	15.0	******	******	******	******	******
421-321	01/25/83	1500	58.0	41.0	17.0	21.0	******	******	******	******	******
422-322	01/26/83	1230	74.0	53.0	19.0	17.0	******	******	******	******	******
422-323	01/26/83	1630	70.0	43.0	******	******	******	******	******	******	******
423-324	01/27/83	1230	62.0	41.0	17.0	******	******	******	******	******	******
423-325	01/27/83	1530	62.0	41.0	17.0	15.0	******	******	******	******	******

Table 2B. (Continued)

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*   CODE   * *  DATE    * *TIME* * COD    * * COD    * * TOC    * * TOC    * * TKN    * * TKN    * *NH3-N   * *NO2-N   * *NO3-N   *
*          * *          * *    * *TOTAL   * *FILTER  * *TOTAL   * *FILTER  * *TOTAL   * *FILTER  * *        * *        * *        *
*          * *          * *    * *(MG/L)  * *(MG/L)  * *(MG/L)  * *(MG/L)  * *(MG/L)  * *(MG/L)  * *(MG/L)  * *(MG/L)  * *(MG/L)  *

    427-326    01/31/83     1145     64.0       31.0       21.0       19.0      14.00      11.00       9.50     ******      0.200
    427-327    01/31/83     1330     57.0       39.0       21.0       15.0      16.00      12.00      12.00     ******      0.260
    427-328    01/31/83     1600     47.0       25.0       17.0       17.0      15.00      13.00      12.00     ******      0.250
    428-329    02/01/83     1130     53.0       29.0       18.0       17.0     ******     ******     ******     ******     ******
    428-330    02/01/83     1330     42.0       22.0       17.0       17.0     ******     ******     ******     ******     ******
    428-331    02/01/83     1700     45.0       28.0       24.0       21.0     ******     ******     ******     ******     ******
    429-332    02/02/83     1100     70.0       33.0       18.0       24.0     ******     ******     ******     ******     ******
    429-333    02/02/83     1500     51.0       22.0       21.0       15.0     ******     ******     ******     ******     ******
    430-334    02/03/83     1200     43.0       29.0       25.0       17.0     ******     ******     ******     ******     ******
    430-335    02/03/83     1430     65.0       41.0       25.0       19.0     ******     ******     ******     ******     ******
    441-336    02/09/83              50.0       23.0       42.0       30.0     ******       1.70      12.00     ******      0.500
    444-337    02/17/83     1200     77.0       21.0       29.0       28.0     ******     ******     ******     ******     ******
    444-338    02/17/83              55.0       25.0       33.0       30.0     ******     ******     ******     ******     ******
    455-339    02/28/83              50.0       29.0       26.0       26.0       8.00       6.00       6.10     ******      0.170
    455-340    02/28/83              48.0       25.0       32.0       31.0      11.00       8.80      10.00     ******      0.260
    462-341    03/07/83     1100     61.0       34.0       24.0       24.0       7.70       7.80       7.80     ******      0.220
    462-342    03/07/83     1230     55.0       26.0       22.0       22.0       9.30       8.20       7.80     ******      0.270
    462-343    03/07/83     1430     55.0       26.0       23.0       19.0      12.00     ******      10.00     ******      0.200
    463-344    03/08/83     1115     53.0       46.0       30.0       28.0     ******     ******     ******     ******     ******
    463-345    03/08/83     1230     52.0       42.0       22.0       27.0     ******     ******     ******     ******     ******
    463-346    03/08/83      CSO   ******     ******     ******     ******     ******     ******     ******     ******     ******
    464-347    03/09/83              49.0       38.0       25.0       24.0     ******     ******     ******     ******     ******
    464-348    03/09/83              50.0       38.0       22.0       23.0     ******     ******     ******     ******     ******
    464-349    03/09/83              49.0       41.0       23.0       24.0     ******     ******     ******     ******     ******
    469-350    03/14/83     1200     34.0       23.0       33.0       27.0     ******     ******     ******     ******     ******
    469-351    03/14/83     1400     31.0       22.0       30.0       28.0     ******     ******     ******     ******     ******
    470-352    03/15/83              36.0       23.0       36.0       29.0     ******     ******     ******     ******     ******
    470-353    03/15/83              30.0       26.0       30.0       31.0     ******     ******     ******     ******     ******
    471-354    03/16/83     1130     32.0       29.0       32.0       29.0     ******     ******     ******     ******     ******
    471-355    03/16/83     1430     34.0       27.0       35.0       30.0     ******     ******     ******     ******     ******
    472-356    03/17/83     1130     37.0       28.0       36.0       31.0     ******     ******     ******     ******     ******
    472-357    03/17/83     1500     39.0       32.0       35.0     ******     ******     ******     ******     ******     ******
    476-358    03/21/83      CSO   ******     ******     ******     ******     ******     ******     ******     ******     ******
    476-359    03/21/83      CSO   ******     ******     ******     ******     ******     ******     ******     ******     ******
    477-360    03/22/83              43.0       34.0       22.0       25.0     ******     ******     ******     ******     ******
    477-361    03/22/83     1500     44.0       31.0       22.0       21.0     ******     ******     ******     ******     ******
    478-362    03/23/83     1430     33.0       27.0       20.0       21.0     ******     ******     ******     ******     ******
    479-363    03/24/83     1100     67.0       47.0       25.0       24.0     ******     ******     ******     ******     ******
    483-364    03/28/83     1130     57.0       17.0       30.0       15.0     ******     ******     ******     ******     ******
    483-365    03/28/83     1500     31.0       18.0       17.0       19.0     ******     ******     ******     ******     ******
    484-366    03/29/83     1130     44.0       40.0       24.0       27.0     ******     ******     ******     ******     ******
    484-367    03/29/83     1500     38.0       31.0       19.0       23.0     ******     ******     ******     ******     ******
    497-368    04/11/83              22.0       17.0       31.0       19.0     ******     ******     ******     ******     ******
    497-369    04/11/83              22.0       26.0       18.0       24.0     ******     ******     ******     ******     ******
    497-370    04/11/83              23.0       18.0       23.0       21.0     ******     ******     ******     ******     ******
    498-371    04/12/83     1030     52.0       29.0       24.0       22.0     ******     ******     ******     ******     ******
    498-372    04/12/83     1300     36.0       29.0       37.0       25.0     ******     ******     ******     ******     ******
    498-373    04/12/83     1600     26.0       23.0       26.0       15.0     ******     ******     ******     ******     ******
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Table 2B. (Continued)

CODE	DATE	TIME	COD TOTAL (MG/L)	COD FILTER (MG/L)	TOC TOTAL (MG/L)	TOC FILTER (MG/L)	TKN TOTAL (MG/L)	TKN FILTER (MG/L)	NH3-N (MG/L)	NO2-N (MG/L)	NO3-N (MG/L)
499-374	04/13/83		32.0	25.0	25.0	29.0	******	******	******	******	******
499-375	04/13/83		26.0	22.0	35.0	27.0	******	******	******	******	******
499-376	04/13/83		22.0	16.0	28.0	28.0	******	******	******	******	******
500-377	04/14/83	0800	72.0	30.0	40.0	31.0	******	******	******	******	******
500-378	04/14/83	0925	45.0	30.0	30.0	25.0	******	******	******	******	******
500-379	04/14/83	1100	45.0	30.0	28.0	32.0	******	******	******	******	******
500-380	04/14/83	1415	37.0	32.0	32.0	18.0	******	******	******	******	******
500-381	04/14/83	1515	44.0	26.0	42.0	34.0	******	******	******	******	******
500-382	04/14/83	1600	35.0	28.0	36.0	21.0	******	******	******	******	******
504-383	04/18/83	1300	30.0	19.0	10.0	12.0	******	******	******	******	******
504-384	04/18/83	1500	30.0	19.0	8.0	10.0	******	******	******	******	******
504-385	04/18/83	1700	28.0	19.0	13.0	10.0	******	******	******	******	******
505-386	04/19/83	1200	30.0	18.0	12.0	11.0	******	******	******	******	******
505-387	04/19/83	1400	31.0	22.0	14.0	9.0	******	******	******	******	******
505-388	04/19/83	1600	37.0	25.0	22.0	10.0	******	******	******	******	******
506-389	04/20/83		34.0	18.0	9.0	13.0	******	******	******	******	******
506-390	04/20/83		33.0	17.0	12.0	9.0	******	******	******	******	******
506-391	04/20/83		33.0	24.0	15.0	9.0	******	******	******	******	******
507-392	04/21/83		40.0	31.0	14.0	10.0	******	******	******	******	******
507-393	04/21/83		34.0	26.0	12.0	14.0	******	******	******	******	******
507-394	04/21/83		36.0	25.0	10.0	******	******	******	******	******	******
507-395	04/21/83		30.0	21.0	12.0	14.0	******	******	******	******	******
507-396	04/21/83		29.0	19.0	14.0	10.0	******	******	******	******	******
507-397	04/21/83		28.0	18.0	13.0	******	******	******	******	******	******
511-398	04/25/83	1100	******	******	******	******	******	******	******	******	******
511-399	04/25/83	1200	21.0	20.0	15.0	14.0	******	******	******	******	******
511-400	04/25/83	1500	******	******	******	******	******	******	******	******	******
512-401	04/26/83	1230	******	******	******	******	******	******	******	******	******
512-402	04/26/83	1400	21.0	22.0	11.0	******	******	******	******	******	******
512-403	04/26/83	1530	******	******	******	******	******	******	******	******	******
513-404	04/27/83	1000	******	******	******	******	******	******	******	******	******
513-405	04/27/83	1130	37.0	34.0	******	10.0	******	******	******	******	******
513-406	04/27/83	1530	******	******	******	******	******	******	******	******	******
514-407	04/28/83	1100	******	******	******	******	******	******	******	******	******
514-408	04/28/83	1300	45.0	26.0	15.0	******	******	******	******	******	******
514-409	04/28/83	1500	******	******	******	******	******	******	******	******	******
520-410	05/04/83	1100	******	******	******	******	******	******	******	******	******
520-411	05/04/83	1300	56.0	44.0	******	******	******	******	******	******	******
520-412	05/04/83	1530	******	******	******	******	******	******	******	******	******
521-413	05/05/83	1200	******	******	******	******	******	******	******	******	******
521-414	05/05/83	1330	62.0	34.0	16.0	13.0	******	******	******	******	******
521-415	05/05/83	1500	******	******	******	******	******	******	******	******	******
574-416	06/27/83		26.0	28.0	11.0	******	******	******	******	******	******
574-417	06/27/83		******	******	******	******	******	******	******	******	******
574-418	06/27/83		******	******	******	******	******	******	******	******	******
575-419	06/28/83		29.0	25.0	8.0	9.0	******	******	******	******	******
575-420	06/28/83		******	******	******	******	******	******	******	******	******
575-421	06/28/83		******	******	******	******	******	******	******	******	******

Table 2B. (Continued)

CODE	DATE	TIME	COD TOTAL (MG/L)	COD FILTER (MG/L)	TOC TOTAL (MG/L)	TOC FILTER (MG/L)	TKN TOTAL (MG/L)	TKN FILTER (MG/L)	NH3-N (MG/L)	NO2-N (MG/L)	NO3-N (MG/L)
576-422	06/29/83		38.0	36.0	12.0	22.0	******	******	******	******	******
576-423	06/29/83		******	******	******	******	******	******	******	******	******
576-424	06/29/83		******	******	******	******	******	******	******	******	******
577-425	06/30/83		29.0	26.0	7.0	17.0	******	******	******	******	******
577-426	06/30/83		******	******	******	******	******	******	******	******	******
577-427	06/30/83		******	******	******	******	******	******	******	******	******
589-428	07/12/83	1100	37.0	26.0	16.0	9.0	******	******	******	******	******
589-429	07/12/83	1300	******	******	******	******	******	******	******	******	******
589-430	07/12/83	1515	******	******	******	******	******	******	******	******	******
590-431	07/13/83	1100	42.0	33.0	12.0	9.0	******	******	******	******	******
590-432	07/13/83	1315	******	******	******	******	******	******	******	******	******
590-433	07/13/83	1530	******	******	******	******	******	******	******	******	******
591-434	07/14/83		33.0	33.0	12.0	7.0	******	******	******	******	******
591-435	07/14/83		******	******	******	******	******	******	******	******	******
591-436	07/14/83		******	******	******	******	******	******	******	******	******
595-437	07/18/83	1000	32.0	29.0	12.0	8.0	******	******	******	******	******
595-438	07/18/83	1215	******	******	******	******	******	******	******	******	******
595-439	07/18/83	1500	******	******	******	******	******	******	******	******	******
596-440	07/19/83	1030	53.0	40.0	14.0	10.0	******	******	******	******	******
596-441	07/19/83	1330	******	******	******	******	******	******	******	******	******
597-442	07/20/83	1100	52.0	40.0	15.0	10.0	******	******	******	******	******
602-443	07/25/83	1200	57.0	35.0	15.0	14.0	******	******	******	******	******
602-444	07/25/83	1530	******	******	******	******	******	******	******	******	******
603-445	07/26/83	1005	75.0	58.0	20.0	17.0	******	******	******	******	******
603-446	07/26/83	1300	******	******	******	******	******	******	******	******	******
603-447	07/26/83	1615	******	******	******	******	******	******	******	******	******
604-448	07/27/83	0845	55.0	35.0	17.0	14.0	******	******	******	******	******
604-449	07/27/83	1130	******	******	******	******	******	******	******	******	******
604-450	07/27/83		******	******	******	******	******	******	******	******	******
605-451	07/28/83		72.0	50.0	21.0	16.0	******	******	******	******	******
605-452	07/28/83		******	******	******	******	******	******	******	******	******
605-453	07/28/83		******	******	******	******	******	******	******	******	******
609-454	08/01/83	1000	37.0	30.0	19.0	16.0	******	******	******	******	******
609-455	08/01/83	1130	******	******	******	******	******	******	******	******	******
609-456	08/01/83	1400	******	******	******	******	******	******	******	******	******
610-457	08/02/83	0930	33.0	25.0	16.0	19.0	******	******	******	******	******
610-458	08/02/83	1115	******	******	******	******	******	******	******	******	******
610-459	08/02/83	1500	******	******	******	******	******	******	******	******	******
611-460	08/03/83	0930	38.0	37.0	17.0	******	******	******	******	******	******
611-461	08/03/83	1230	******	******	******	******	******	******	******	******	******
611-462	08/03/83	1500	******	******	******	******	******	******	******	******	******
612-463	08/04/83	0945	37.0	32.0	17.0	20.0	******	******	******	******	******
612-464	08/04/83	1330	******	******	******	******	******	******	******	******	******
612-465	08/04/83	1345	******	******	******	******	******	******	******	******	******
616-466	08/08/83	0935	29.0	26.0	13.0	14.0	******	******	******	******	******
616-467	08/08/83	1145	******	******	******	******	******	******	******	******	******
616-468	08/08/83	1500	******	******	******	******	******	******	******	******	******
617-469	08/09/83	0945	25.0	25.0	18.0	15.0	******	******	******	******	******

Table 2B. (Continued)

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*   CODE   * *  DATE   *  *TIME*  * COD  * * COD   * * TOC  * * TOC   * * TKN  * * TKN   * *NH3-N * *NO2-N * *NO3-N *
*          * *         *  *    *  *TOTAL * *FILTER* *TOTAL * *FILTER* *TOTAL * *FILTER* *      * *      * *      *
*          * *         *  *    *  *(MG/L)* *(MG/L)* *(MG/L)* *(MG/L)* *(MG/L)* *(MG/L)* *(MG/L)* *(MG/L)* *(MG/L)*

    617-470     08/09/83     1200   ******    ******    ******    ******    ******    ******    ******    ******    ******
    617-471     08/09/83     1500   ******    ******    ******    ******    ******    ******    ******    ******    ******
    618-472     08/10/83     1000     25.0      26.0      17.0      15.0    ******    ******    ******    ******    ******
    618-473     08/10/83     1200   ******    ******    ******    ******    ******    ******    ******    ******    ******
    618-474     08/10/83     1400   ******    ******    ******    ******    ******    ******    ******    ******    ******
    619-475     08/11/83     0925     28.0      25.0      12.0      12.0    ******    ******    ******    ******    ******
    619-476     08/11/83     1130   ******    ******    ******    ******    ******    ******    ******    ******    ******
    619-477     08/11/83     1430   ******    ******    ******    ******    ******    ******    ******    ******    ******
    630-478     08/22/83     1000     22.0      21.0       8.0       5.0    ******    ******    ******    ******    ******
    630-479     08/22/83     1200   ******    ******    ******    ******    ******    ******    ******    ******    ******
    631-480     08/23/83     1000     28.0      24.0       7.0       6.0    ******    ******    ******    ******    ******
    631-481     08/23/83     1200   ******    ******    ******    ******    ******    ******    ******    ******    ******
    632-482     08/24/83              30.0      23.0       9.0       5.0    ******    ******    ******    ******    ******
    632-483     08/24/83            ******    ******    ******    ******    ******    ******    ******    ******    ******
    633-484     08/25/83     1000     34.0      22.0      10.0       7.0    ******    ******    ******    ******    ******
    633-485     08/25/83     1330   ******    ******    ******    ******    ******    ******    ******    ******    ******
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Table 2B. (Continued)

CODE DAY NO	DATE	TIME	WIPER RATE (CPH)	LAMP TEMP (C)	LAMPS ON	VOLTAGE (%)	I METER A (%)	I METER B (%)	I METER C (%)	IL 570 INF W/CM2	IL 570 EFF W/CM2
002	12/02/81	0900	****	****	100	90	****	****	****	0.00E 00	0.00E 00
003	12/03/81	0800	****	****	100	90	****	****	****	0.00E 00	0.00E 00
007	12/07/81	0930	6.	****	100	90	****	****	****	0.00E 00	0.00E 00
014	12/14/81	1415	6.	****	100	90	38.	35.	32.	0.00E 00	0.00E 00
015	12/15/81	1000	6.	****	100	90	38.	32.	32.	0.00E 00	0.00E 00
016	12/16/81	1000	6.	****	100	90	36.	32.	32.	0.00E 00	0.00E 00
017	12/17/81	0800	6.	****	100	90	40.	34.	34.	0.00E 00	0.00E 00
021	12/21/81	0930	****	****	100	90	32.	30.	30.	0.00E 00	0.00E 00
023	12/23/81	1000	6.	****	99	90	40.	34.	34.	0.00E 00	0.00E 00
028	12/28/81	0800	6.	****	99	90	40.	34.	34.	0.00E 00	0.00E 00
029	12/29/81	0830	6.	****	99	90	38.	34.	34.	0.00E 00	0.00E 00
035	01/04/82	0930	6.	****	99	90	39.	32.	35.	0.00E 00	0.00E 00
037	01/06/82	0700	****	****	100	90	39.	32.	34.	0.00E 00	0.00E 00
038	01/07/82	0630	6.	****	100	90	38.	34.	36.	0.00E 00	0.00E 00
041	01/11/82	1315	6.	****	100	90	38.	32.	32.	0.00E 00	0.00E 00
042	01/12/82	0930	6.	****	100	90	39.	30.	33.	0.00E 00	0.00E 00
051	01/20/82	0930	6.	****	100	90	39.	29.	32.	0.00E 00	0.00E 00
058	01/27/82	0900	****	****	0	0	****	****	****	0.00E 00	0.00E 00
059	01/28/82	1000	****	****	0	0	****	****	****	0.00E 00	0.00E 00
066	02/04/82	0930	6.	****	100	90	60.	20.	22.	0.00E 00	0.00E 00
071	02/09/82	1100	6.	22.7	100	90	65.	18.	20.	0.00E 00	0.00E 00
072	02/10/82	0900	6.	21.6	100	90	****	98.	****	0.00E 00	0.00E 00
073	02/11/82	1030	6.	22.2	100	90	****	96.	****	0.00E 00	0.00E 00
078	02/16/82	1100	6.	22.2	100	90	****	86.	****	0.00E 00	0.00E 00
079	02/17/82	0930	6.	23.3	100	90	****	79.	****	0.00E 00	0.00E 00
086	02/24/82	0930	6.	****	97	90	67.	18.	16.	0.22E-04	0.39E-04
087	02/25/82	0930	6.	****	97	90	44.	18.	18.	0.11E-03	0.66E-04
091	03/01/82	1330	12.	****	98	90	32.	16.	18.	0.19E-03	0.25E-04
092	03/02/82	1000	12.	****	98	90	28.	16.	16.	0.69E-04	0.12E-03
093	03/03/82	1015	12.	****	98	90	22.	16.	16.	0.20E-04	0.74E-04
094	03/04/82	1015	12.	****	97	90	20.	16.	16.	0.25E-04	0.12E-03
098	03/08/82	1415	12.	****	97	90	20.	16.	16.	0.95E-04	0.30E-03
099	03/09/82	0930	12.	****	97	90	20.	16.	16.	0.00E 00	0.00E 00
100	03/10/82	1100	12.	****	97	90	40.	32.	30.	0.19E-04	0.11E-03
105	03/15/82	1330	12.	****	96	100	44.	36.	32.	0.11E-03	0.42E-03
106	03/16/82	1130	****	****	0	0	****	****	****	0.00E 00	0.00E 00
107	03/17/82	1315	****	****	0	0	****	****	****	0.00E 00	0.00E 00
149	04/28/82	1115	6.	62.2	99	85	42.	32.	32.	0.38E-04	0.13E-03
150	04/29/82	1100	6.	62.2	99	100	****	****	****	0.00E 00	0.00E 00
154	05/03/82	1330	6.	61.1	96	100	42.	40.	32.	0.12E-03	0.30E-03
155	05/04/82	1130	6.	61.7	96	100	42.	30.	30.	0.65E-04	0.15E-04
156	05/05/82	1400	6.	61.7	96	100	****	****	****	0.00E 00	0.00E 00
157	05/06/82	1430	6.	63.3	95	100	40.	28.	32.	0.00E 00	0.17E-03
161	05/10/82	1400	6.	61.7	92	100	40.	29.	32.	0.00E 00	0.37E-03
162	05/11/82		6.	61.7	92	100	****	****	****	0.00E 00	0.00E 00
168	05/17/82		6.	****	94	100	****	****	****	0.00E 00	0.00E 00
169	05/18/82	1045	6.	63.3	94	100	27.	38.	29.	0.00E 00	0.00E 00

Table 3. Unit 1 (Widely Spaced Quartz System) Operating Conditions

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*   CODE    * *  DATE   * *TIME* *WIPER* *LAMP* *LAMPS* *VOLTAGE* *  I   * *  I   * *  I   * * IL   * * IL   *
*           * *         * *    * *RATE * *TEMP* * ON  * *       * *METER* *METER* *METER* * 570  * * 570  *
* DAY NO    * *         * *    * *(CPH)* * (C)* *     * *       * *  A   * *  B   * *  C   * * INF  * * EFF  *
*           * *         * *    * *     * *    * *     * *   (%) * * (%)  * * (%)  * * (%)  * *W/CM2* *W/CM2*

    171        05/20/82    1015     6.     62.8     95       100      40.      30.      32.   0.00E 00  0.00E 00
    176        05/25/82             1.     ****     99       100     ****     ****     ****   0.00E 00  0.40E-03
    177        05/26/82    1000   ****     ****     99       100     ****     ****     ****   0.00E 00  0.34E-03
    183        06/01/82    1000     1.     ****     86       100     ****     ****     ****   0.00E 00  0.42E-03
    196        06/14/82             1.     ****     96       100      41.      30.      36.   0.00E 00  0.47E-03
    197        06/15/82             1.     ****     97       100      40.      32.      30.   0.00E 00  0.52E-03
    198        06/16/82             1.     ****     98       100      40.      36.      30.   0.00E 00  0.72E-03
    203        06/21/82    1100     1.     ****     96       100     ****     ****     ****   0.00E 00  0.59E-03
    204        06/22/82    1000     1.     ****     95       100     ****     ****     ****   0.00E 00  0.57E-03
    205        06/23/82    1000     1.     ****     96       100     ****     ****     ****   0.00E 00  0.34E-03
    210        06/28/82    0930     1.     ****     97       100     ****     ****     ****   0.00E 00  0.61E-03
    211        06/29/82    0800     1.     50.5     97       100     ****     ****     ****   0.00E 00  0.39E-03
    212        06/30/82    0800     1.     62.2     97       100     ****     ****     ****   0.00E 00  0.35E-03
    218        07/06/82    0830     1.     61.7     97       100     ****     ****     ****   0.00E 00  0.44E-03
    219        07/07/82             1.     ****     97       100     ****     ****     ****   0.00E 00  0.00E 00
    225        07/13/82    0830     1.     ****     97        90     ****     ****     ****   0.00E 00  0.39E-03
    226        07/14/82    0930     1.     68.9     96       100     ****     ****     ****   0.00E 00  0.72E-03
    231        07/19/82    0900     1.     68.3     96       100     ****     ****     ****   0.00E 00  0.61E-03
    239        07/27/82    0830     1.     67.8     94       100     ****     ****     ****   0.00E 00  0.38E-03
    240        07/28/82    0830     1.     67.8     95       100     ****     ****     ****   0.00E 00  0.29E-03
    241        07/29/82    0800     1.     68.9     95       100     ****     ****     ****   0.00E 00  0.44E-03
    245        08/02/82    0830     1.     67.8     95       100     ****     ****     ****   0.00E 00  0.72E-03
    246        08/03/82    0800     1.     67.8     95       100     ****     ****     ****   0.00E 00  0.00E 00
    247        08/04/82    0800     1.     67.8     95       100     ****     ****     ****   0.00E 00  0.00E 00
    252        06/09/82    0830     0.     66.1     95       100     ****     ****     ****   0.00E 00  0.74E-03
    253        08/10/82    0730     0.     66.7     93       100     ****     ****     ****   0.00E 00  0.21E-03
    254        08/11/82    0900     0.     66.7     92       100     ****     ****     ****   0.00E 00  0.26E-03
    260        08/17/82    1015     1.     ****     88       100     ****     ****     ****   0.15E-03  0.35E-03
    266        08/23/82    0850   ****     ****      0         0     ****     ****     ****   0.00E 00  0.00E 00
    267        08/24/82    0800   ****     ****      0         0     ****     ****     ****   0.00E 00  0.00E 00
    268        08/25/82    0750   ****     ****      0         0     ****     ****     ****   0.00E 00  0.00E 00
    274        08/31/82           ****     ****      0         0     ****     ****     ****   0.00E 00  0.00E 00
    275        09/01/82    1530     1.     ****     85       100     ****     ****     ****   0.00E 00  0.00E 00
    281        09/07/82    0930   ****     ****      0         0     ****     ****     ****   0.00E 00  0.00E 00
    282        09/08/82           ****     ****      0         0     ****     ****     ****   0.00E 00  0.00E 00
    296        09/22/82    1200   ****     ****      0         0     ****     ****     ****   0.00E 00  0.00E 00
    308        10/04/82    1200     1.     66.1     98       100     ****     ****     ****   0.23E-03  0.31E-03
    309        10/05/82    1000     1.     65.6     98       100     ****     ****     ****   0.12E-03  0.17E-03
    310        10/06/82    1015     1.     66.1     98       100     ****     ****     ****   0.18E-03  0.19E-03
    315        10/12/82    1430     1.     65.0     98       100     ****     ****     ****   0.54E-03  0.35E-03
    316        10/13/82    1100     1.     65.0     98       100     ****     ****     ****   0.00E 00  0.31E-05
    321        10/18/82    1200   ****     ****      0         0     ****     ****     ****   0.00E 00  0.00E 00
    322        10/19/82    1000   ****     ****      0         0     ****     ****     ****   0.00E 00  0.00E 00
    329        10/25/82    1610     1.     ****     92       100     ****     ****     ****   0.12E-02  0.10E-04
    330        10/26/82    1215     1.     ****     92       100     ****     ****     ****   0.20E-03  0.00E 00
    331        10/27/82    1130     1.     ****     92       100     ****     ****     ****   0.15E-03  0.00E 00
    337        11/02/82    1000     1.     ****     92       100     ****     ****     ****   0.33E-04  0.00E 00
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Table 3. (Continued)

CODE DAT NO	DATE	TIME	WIPER RATE (CPH)	LAMP TEMP (C)	LAMPS ON	VOLTAGE (%)	I METER A (%)	I METER B (%)	I METER C (%)	IL 570 INF W/CM2	IL 570 EFF W/CM2
338	11/03/82	1000	1.	****	90	100	****	****	****	0.56E-04	0.00E 00
343	11/08/82	1300	1.	****	90	100	****	****	****	0.00E 00	0.00E 00
345	11/10/82	1000	1.	****	90	100	****	****	****	0.00E 00	0.13E-03
350	11/15/82	1130	1.	****	52	100	****	****	****	0.00E 00	0.27E-03
351	11/16/82	1030	1.	****	52	100	****	****	****	0.00E 00	0.23E-03
352	11/17/82	1130	1.	****	52	100	****	****	****	0.00E 00	0.50E-04
353	11/18/82	1145	1.	****	52	100	****	****	****	0.00E 00	0.85E-04
357	11/22/82	1430	1.	****	52	100	****	****	****	0.00E 00	0.20E-03
358	11/23/82	1100	1.	****	52	100	****	****	****	0.00E 00	0.54E-04
364	11/29/82	1100	1.	****	90	100	****	****	****	0.00E 00	0.18E-03
365	11/30/82	1300	1.	****	90	100	****	****	****	0.08E 00	0.13E-03
366	12/01/82	1145	1.	****	90	100	****	****	****	0.00E 00	0.59E-04
367	12/02/82	1200	1.	****	90	100	****	****	****	0.00E 00	0.13E-03
371	12/06/82	1200	****	****	0	0	****	****	****	0.00E 00	0.00E 00
372	12/07/82	113r	****	****	0	0	****	****	****	0.00E 00	0.00E 00
373	12/08/82	1130	****	****	0	0	****	****	****	0.00E 00	0.00E 00
378	12/13/82	1200	****	****	0	0	****	****	****	0.00E 00	0.00E 00
379	12/14/82	1130	****	****	88	100	****	****	****	0.00E 00	0.24E-04
380	12/15/82	1430	1.	****	94	100	****	****	****	0.00E 00	0.73E-04
381	12/16/82	1200	1.	****	94	100	****	****	****	0.00E 00	0.00E 00
385	12/20/82	1130	1.	****	94	100	****	****	****	0.00E 00	0.00E 00
386	12/21/82	1115	1.	****	94	100	****	****	****	0.00E 00	0.00E 00
399	01/03/83	1230	1.	****	94	100	****	****	****	0.00E 00	0.00E 00
400	01/04/83	1030	1.	****	94	100	****	****	****	0.00E 00	0.00E 00
401	01/05/83	1145	1.	****	92	100	****	****	****	0.00E 00	0.00E 00
402	01/06/83	1030	1.	****	92	100	****	****	****	0.00E 00	0.00E 00
406	01/10/83	1330	1.	****	92	100	****	****	****	0.00E 00	0.21E-03
407	01/11/83	1200	1.	****	92	100	****	****	****	0.00E 00	0.27E-03
408	01/12/83	1045	1.	****	92	100	****	****	****	0.00E 00	0.23E-03
409	01/13/83	1145	****	52.2	92	100	****	****	****	0.00E 00	0.60E-04
413	01/17/83	1500	****	53.3	92	100	****	****	****	0.00E 00	0.22E-03
414	01/18/83	1030	****	53.9	92	100	****	****	****	0.00E 00	0.11E-03
415	01/19/83	1200	****	53.0	94	100	****	****	****	0.00E 00	0.60E-04
416	01/20/83	1200	****	53.9	94	100	****	****	****	0.00E 00	0.40E-04
420	01/24/83	1245	****	52.2	94	100	****	****	****	0.00E 00	0.16E-03
421	01/25/83	1100	****	53.3	94	100	****	****	****	0.00E 00	0.45E-04
422	01/26/83	1200	1.	53.0	94	100	****	****	****	0.00E 00	0.00E 00
423	01/27/83	1200	1.	53.9	94	100	****	****	****	0.00E 00	0.00E 00
427	01/31/83	1130	1.	53.3	94	100	****	****	****	0.00E 00	0.00E 00
428	02/01/83		1.	53.9	94	100	****	****	****	0.00E 00	0.00E 00
429	02/02/83		1.	54.4	94	100	****	****	****	0.00E 00	0.00E 00
430	02/03/83		1.	52.8	94	100	****	****	****	0.00E 00	0.00E 00
441	02/14/83	1230	1.	****	92	100	****	****	****	0.00E 00	0.00E 00
444	02/17/83	1130	1.	****	92	100	****	****	****	0.00E 00	0.00E 00
455	02/28/83	1100	1.	****	92	100	****	****	****	0.00E 00	0.00E 00
462	03/07/83	1100	****	****	0	0	****	****	****	0.00E 00	0.00E 00
463	03/08/83	1100	****	****	0	0	****	****	****	0.00E 00	0.00E 00

Table 3. (Continued)

CODE DAY NO	DATE	TIME	WIPER RATE (CPH)	LAMP TEMP (C)	LAMPS ON	VOLTAGE (%)	I METER A (%)	I METER B (%)	I METER C (%)	IL 570 INF W/CM2	IL 570 EFF W/CM2
464	03/09/83	1100	****	****	0	0	****	****	****	0.00E 00	0.00E 00
469	03/14/83	1145	****	****	0	0	****	****	****	0.00E 00	0.00E 00
470	03/15/83	0900	****	****	0	0	****	****	****	0.00E 00	0.00E 00
471	03/16/83	0900	****	****	0	0	****	****	****	0.00E 00	0.00E 00
472	03/17/83	1100	****	****	0	0	****	****	****	0.00E 00	0.00E 00
476	03/21/83	1130	1.	****	94	100	****	****	****	0.00E 00	0.29E-04
477	03/22/83	1130	1.	****	9A	100	****	****	****	0.00E 00	0.29E-03
478	03/23/83	1415	1.	****	98	100	****	****	****	0.00E 00	0.26E-03
479	03/24/83	1045	1.	****	98	100	****	****	****	0.00E 00	0.23E-03
483	03/28/83	1C30	1.	****	98	100	****	****	****	0.00E 00	0.54E-03
484	03/28/83	0900	1.	****	98	100	****	****	****	0.00E 00	0.25E-03
497	04/11/83	1300	1.	****	98	100	****	****	****	0.00E 00	0.55E-03
498	04/12/83	1000	1.	****	98	100	****	****	****	0.00E 00	0.44E-03
499	04/13/83	1115	1.	****	99	100	****	****	****	0.00E 00	0.62E-03
500	04/14/83		****	****	0	0	****	****	****	0.00E 00	0.00E 00
504	04/18/83	1200	1.	****	98	100	****	****	****	0.00E 00	0.36E-03
505	04/19/83	1030	1.	****	98	100	****	****	****	0.00E 00	0.34E-03
506	04/20/83	1000	1.	****	98	100	****	****	****	0.00E 00	0.55E-03
507	04/21/83	1145	1.	****	96	100	****	****	****	0.00E 00	0.18E-03
511	04/25/83	1000	****	****	0		****	****	****	0.00E 00	0.00E 00
512	04/26/83	1000	****	****	0		****	****	****	0.00E 00	0.00E 00
513	04/27/83	0930	****	****	0	0	****	****	****	0.00E 00	0.00E 00
514	04/28/83	0900	1.	****	96	100	****	****	****	0.00E 00	0.00E 00
520	05/04/83	1115	1.	****	96	100	****	****	****	0.00E 00	0.00E 00
521	05/05/83	1130	1.	****	96	100	****	****	****	0.00E 00	0.00E 00
574	06/27/83		****	****	0	0	****	****	****	0.00E 00	0.00E 00
575	06/28/83	0900	****	****	0	0	****	****	****	0.00E 00	0.00E 00
576	06/29/83	0630	****	****	0	0	****	****	****	0.00E 00	0.00E 00
577	06/30/83	1100	****	****	0	0	****	****	****	0.00E 00	0.00E 00
589	07/12/83	1000	1.	****	40	100	****	****	****	0.00E 00	0.00E 00
590	07/13/83	1030	1.	****	40	100	****	****	****	0.29E-03	0.00E 00
591	07/13/83	1030	1.	****	40	100	****	****	****	0.41E-03	0.00E 00
595	07/18/83	1000	1.	****	58	100	****	****	****	0.56E-03	0.00E 00
596	07/19/83	1013	1.	****	58	100	****	****	****	0.13E-04	0.00E 00
597	07/20/83	1045	1.	****	58	100	****	****	****	0.24E-04	0.00E 00
602	07/25/83	1030	1.	****	58	100	****	****	****	0.51E-04	0.00E 00
603	07/26/83	0915	1.	****	58	100	****	****	****	0.45E-04	0.00E 00
604	07/27/83	0845	1.	****	58	100	****	****	****	0.82E-04	0.00E 00
605	07/25/83	1030	1.	****	58	100	****	****	****	0.95E-04	0.00E 00
609	08/01/83	0915	1.	****	58	100	****	****	****	0.45E-02	0.00E 00
610	08/02/83	0905	1.	****	58	100	****	****	****	0.30E-02	0.00E 00
611	08/03/83	0910	1.	****	58	100	****	****	****	0.65E-02	0.00E 00
612	08/04/83	0915	1.	****	58	100	****	****	****	0.45E-02	0.00E 00
616	08/08/83	0930	1.	****	58	100	****	****	****	0.70E-02	0.00E 00
617	08/09/83	0930	1.	****	58	100	****	****	****	0.60E-02	0.00E 00
618	08/10/83	0930	1.	****	58	100	****	****	****	0.77E-02	0.00E 00
619	08/11/83	0910	1.	****	58	100	****	****	****	0.71E-02	0.00E 00

Table 3. (Continued)

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*   CODE     * *   DATE    *  *TIME*  *WIPER*  *LAMP*  *LAMPS*  *VOLTAGE*   *  I   *  *  I   *  *  I   *  * IL   *  * IL   *
*            * *           *  *    *  *RATE *  *TEMP*  * ON  *  *        *   *METER*  *METER*  *METER*  * 570  *  * 570  *
* DAY NO     * *           *  *    *  *(CPH)*  * (C)*  *     *  *        *   *  A   *  *  B   *  *  C   *  . INF  *  * EFF  *
*            * *           *  *    *  *     *  *    *  *     *  *    (%) *   * (%)  *  * (%)  *  * (%)  *  *W/CM2*  *W/CM2*

    630          08/22/83     0900    ****      ****        0          0       ****      ****      ****     0.00E 00   0.00E 00
    631          08/23/83     1000    ****      ****        0          0       ****      ****      ****     0.00E 00   0.00E 00
    632          08/24/83             ****      ****        0          0       ****      ****      ****     0.00E 00   0.00E 00
    633          08/25/83     1200     1.       ****       58        100       ****      ****      ****     0.00E 00   0.00E 00
    637          08/29/83     1030     1.       ****       58        100       ****      ****      ****     0.00E 00   0.00E 00
    638          08/30/83     1115     1.       ****       58        100       ****      ****      ****     0.15E-05   0.00E 00
    639          08/31/83     1130     1.       ****       58        100       ****      ****      ****     0.91E-02   0.00E 00
    640          09/01/83     1100     1.       ****       58        100       ****      ****      ****     0.51E-04   0.00E 00
    645          09/06/83     1130     1.       ****       58        100       ****      ****      ****     0.85E-05   0.00E 00
    646          09/07/83     1030     1.       ****       58        100       ****      ****      ****     0.90E-05   0.00E 00
    647          09/08/83     1100     1.       ****       58        100       ****      ****      ****     0.24E-04   0.00E 00
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Table 3. (Continued)

CODE	DATE	TIME	FLOW L/MIN	VOLTAGE (%)	BANKS ON	LAMPS ON	TOTAL COLI COL/100	FECAL COLI COL/100
002-001-E1	12/02/81	0930	2482.	90	3	100	220.	***********
002-002-E1	12/02/81	1045	1014.	90	3	100	40.	***********
002-003-E1	12/02/81	1200	1638.	90	3	100	38.	***********
002-004-E1	12/02/81	1430	382.	90	3	100	65.	***********
003-005-E1	12/03/81	0830	382.	90	3	100	5000.	***********
003-006-E1	12/03/81	1045	1639.	90	3	100	364.	***********
003-007-E1	12/03/81	1130	2482.	90	3	100	270.	***********
003-008-E1	12/03/81	1300	1014.	90	3	100	250.	***********
007-009-E1	12/07/81	0930	1014.	90	3	100	68.	***********
007-010-E1	12/07/81	1350	1638.	90	3	100	20.	***********
014-012-E1	12/14/81	0800	427.	90	3	100	32.	***********
014-013-E1	12/14/81	1130	1014.	90	3	100	92.	10.
014-014-E1	12/14/81	1415	1999.	90	3	100	2300.	165.
015-015-E1	12/15/81	1030	2482.	90	3	100	640.	***********
016-019-E1	12/16/81	1230	1014.	90	3	100	640.	66.
021-023-E1	12/21/81	0930	382.	90	3	60	100.	14.
021-024-E1	12/21/81	1130	1014.	90	3	100	780.	46.
021-025-E1	12/21/81	1345	1639.	90	3	100	2300.	150.
023-026-E1	12/23/81	1000	2301.	90	3	99	24000.	3600.
023-027-E1	12/23/81	1130	1638.	90	3	99	4500.	1060.
023-028-E1	12/23/81	1330	1014.	90	3	99	4700.	1020.
028-029-E1	12/28/81	0830	465.	90	3	99	497.	50.
028-030-E1	12/28/81	1000	1105.	90	3	98	260.	78.
028-031-E1	12/28/81	1230	2036.	90	3	99	1020.	290.
029-032-E1	12/28/81	0900	2392.	90	3	99	1260.	***********
029-033-E1	12/29/81	1130	416.	90	3	99	265.	142.
029-034-E1	12/29/81	1330	938.	90	3	99	156.	46.
035-035-E1	01/04/82	1000	363.	90	3	99	665.	88.
037-039-E1	01/06/82	0700	915.	90	3	100	300.	80.
037-040-E1	01/06/82	0930	1638.	90	3	100	760.	94.
037-041-E1	01/06/82	1200	382.	90	3	100	17.	6.
041-044-E1	01/11/82	1330	2619.	90	3	100	3500.	447.
042-045-E1	01/12/82	0945	382.	90	3	100	1200.	52.
042-046-E1	01/12/82	1115	1014.	90	3	100	1600.	105.
042-047-E1	01/12/82	1400	1680.	90	3	100	2900.	240.
051-048-E1	01/20/82	1013	446.	90	3	99	1300.	420.
051-050-E1	01/20/82	1315	2573.	90	3	100	35500.	33000.
066-057-E1	02/04/82	1000	268.	90	3	100	1620.	185.
066-058-E1	02/04/82	1330	1226.	90	3	99	3500.	800.
091-077-E1	03/01/82	1230	2482.	90	3	98	1000.	380.
091-078-E1	03/01/82	1400	1294.	90	3	98	***********	52.
092-079-E1	03/02/82	1000	2392.	90	3	98	***********	370.
092-080-E1	03/02/82	1120	556.	90	3	98	***********	32.
092-081-E1	03/02/82	134[illegible]	1256.	90	3	98	***********	148.
093-082-E1	03/03/82	1100	1294.	90	3	98	1600.	420.
093-083-E1	03/03/82	1230	556.	90	3	98	***********	100.
093-084-E1	03/03/82	1400	2301.	90	3	98	***********	1850.
094-085-E1	03/04/82	1030	556.	90	3	97	***********	480.

Table 4. Unit 1 (Widely Spaced Quartz System) Effluent - Secondary

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*   CODE     * *   DATE   * *TIME* *  FLOW  * *VOLTAGE* *BANKS* *LAMPS* * TOTAL  * * FECAL  *
*            * *          * *    * *  L/MIN* *  (%)   * * ON    * *  ON * *  COLI  * *  COLI  *
*            * *          * *    * *       * *        * *       * *     * *COL/100* *COL/100*

094-086-E1     03/04/82    1230    1226.        90         3         97  ***********        93.
094-087-E1     03/04/82    1400    2482.        90         3         97  ***********      1090.
098-088-E1     03/09/82    1115     556.        90         3         97         115.       102.
098-089-E1     03/08/82    1230    1014.        90         3         97         760.       165.
099-091-E1     03/09/82    1000    1998.        90         3         97       29500.      2700.
099-092-E1     03/09/82    1200     261.        90         3         97        1220.        89.
099-093-E1     03/09/82    1430    1063.        90         3         97        4300.      1210.
161-117-E1     05/10/82    1230     382.       100         3         92          26.         6.
161-118-E1     05/10/82    1430    1014.       100         3         92        2900.      1460.
168-119-E1     05/17/82            2036.       100         3         92       12000.      2650.
169-121-E1     05/18/82    1100     556.       100         3         94         126.       115.
169-122-E1     05/18/82    1330    1294.       100         3         96         460.       150.
171-123-E1     05/20/82    1030     556.       100         3         95         100.        18.
176-124-E1     05/25/82    1000     915.       100         3         99          12.         4.
176-125-E1     05/25/82    1230    1423.       100         3         99          16.         6.
176-126-E1     05/25/82    1500    2573.       100         3         99         255.       120.
177-127-E1     05/26/82    1000    1423.       100         3         99  ***********        12.
177-128-E1     05/26/82    1200    1014.       100         3         99          10.         6.
177-129-E1     05/26/82    1500    2573.       100         3         99         530.       140.
183-130-E1     06/01/82    1000    1014.       100         3         86          24.        20.
183-131-E1     06/01/82    1230    1423.       100         3         86          41.        17.
183-132-E1     06/01/82    1450    2573.       100         3         86         238.        75.
196-133-E1     06/14/82            2573.       100         3         97         252.       153.
196-134-E1     06/14/82            1014.       100         3         97          32.        14.
196-135-E1     06/14/82            1423.       100         3         97          53.        22.
197-136-E1     06/15/82             605.       100         3         97         235.        48.
197-137-E1     06/15/82            1294.       100         3         97         980.       255.
203-142-E1     06/21/82    1130    1014.       100         3         96          20.         6.
203-143-E1     06/21/82    1345    1423.       100         3         96          16.         8.
203-144-E1     06/21/82    1600    2573.       100         3         96          15. ***********
204-145-E1     06/22/82    1030    1423.       100         3         95          12.        10.
204-146-E1     06/22/82    1315    2573.       100         3         95          26.        14.
204-147-E1     06/22/82    1600    1014.       100         3         95           7.         4.
205-148-E1     06/23/82    1015    1423.       100         3         96           4.         2.
205-149-E1     06/23/82    1230    1014.       100         3         96           4.         1.
205-150-E1     06/23/82    1500    2573.       100         3         96         420.       300.
210-151-E1     06/28/82    0930    1423.       100         3         97           9.         3.
210-152-E1     06/28/82    1100    2573.       100         3         97          22.        12.
211-154-E1     06/29/82    0815    1014.       100         3         97          12.        12.
211-155-E1     06/29/82    1115    1423.       100         3         97          30.         5.
211-156-E1     06/29/82    1330    2573.       100         3         97          36.        31.
212-157-E1     06/30/82    0830    2573.       100         3         97         107.        24.
212-158-E1     06/30/82    1100    1423.       100         3         97          39.        52.
212-159-E1     06/30/82    1330    1014.       100         3         97          15.         4.
225-164-E1     07/13/82    0900    1423.       100         2         67  ***********        52.
225-165-E1     07/13/82            1014.       100         2         67  ***********        40.
225-166-E1     07/13/82            2573.       100         2         60  ***********       430.
226-167-E1     07/14/82    0900    2573.       100         2         66  ***********       133.
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Table 4. (Continued)

CODE	DATE	TIME	FLOW L/MIN	VOLTAGE (%)	BANKS ON	LAMPS ON	TOTAL COLI COL/100	FECAL COLI COL/100
226-168-E1	07/14/82	1130	1400.	100	2	66	***********	57.
226-169-E1	07/14/82	1400	1014.	100	2	66	***********	13.
231-170-E1	07/19/82		1423.	100	2	66	***********	30.
231-171-E1	07/19/82		2573.	100	2	66	130.	75.
231-172-E1	07/19/82		1014.	100	2	66	17.	15.
239-173-E1	07/27/82	0900	1014.	100	2	64	23.	28.
239-174-E1	07/27/82	1130	1423.	100	2	64	95.	127.
239-175-E1	07/27/82	1400	2573.	100	2	64	530.	440.
240-177-E1	07/28/82	1115	1014.	100	2	65	97.	21.
240-178-E1	07/28/82	1415	1423.	100	2	65	138.	94.
241-179-E1	07/29/82	0830	1014.	100	2	65	56.	11.
245-180-E1	08/02/82	0900	1423.	100	2	65	10.	4.
245-181-E1	08/02/82	1100	2573.	100	2	65	110.	30.
245-182-E1	08/02/82	1330	1014.	100	2	65	***********	***********
246-183-E1	08/03/82	0900	1423.	100	2	65	55.	16.
246-184-E1	08/03/82	1115	1014.	100	2	65	36.	8.
246-185-E1	08/03/82	1330	2573.	100	2	65	2000.	545.
247-186-E1	08/04/82	0900	1423.	100	2	65	62.	58.
247-187-E1	08/04/82	1130	2573.	100	2	65	1500.	385.
247-188-E1	08/04/82	1400	1014.	100	2	65	392.	40.
252-189-E1	08/09/82	0900	1014.	100	2	65	44.	24.
252-190-E1	08/09/82	1130	1423.	100	2	65	49.	39.
252-191-E1	08/09/82	1430	2573.	100	2	65	330.	133.
253-192-E1	08/10/82	0900	1014.	100	2	62	***********	115.
253-193-E1	08/10/82	1130	1423.	100	2	62	***********	290.
253-194-E1	08/10/82	1330	2573.	100	2	62	***********	2450.
254-195-E1	08/11/82	1015	2573.	100	2	62	***********	620.
254-196-E1	08/11/82	1200	1423.	100	2	62	***********	21.
254-197-E1	08/11/82	1400	1014.	100	2	62	***********	14.
308-219-E1	10/04/82	1330	325.	100	3	98	26.	7.
308-220-E1	10/04/82	1600	2482.	100	3	98	125.	90.
309-222-E1	10/05/82		382.	100	3	98	49.	25.
310-223-E1	10/06/82	1100	2482.	100	3	98	125.	86.
310-224-E1	10/06/82	1400	1014.	100	3	98	40.	28.
315-225-E1	10/12/82	1130	1014.	100	3	98	74.	***********
315-226-E1	10/12/82	1515	2482.	100	3	98	190.	55.
330-237-E1	10/26/82		1014.	100	3	92	***********	97.
331-238-E1	10/27/82	1130	2482.	100	3	92	***********	75.
331-239-E1	10/27/82	1330	1014.	100	3	92	***********	24.
337-240-E1	11/02/82	1100	1423.	100	2	58	***********	***********
337-241-E1	11/02/82	1300	1014.	100	2	58	***********	***********
337-242-E1	11/02/82	1500	2482.	100	2	58	***********	***********
338-243-E1	11/03/82	1030	1014.	100	2	58	***********	***********
338-244-E1	11/03/82	1300	1423.	100	2	58	***********	***********
338-245-E1	11/03/82	1500	2482.	100	2	58	***********	***********
428-329-E1	02/01/83	1100	908.	100	3	94	135.	65.
428-330-E1	02/01/83	1330	473.	100	3	94	75.	45.
428-331-E1	02/01/83	1700	1835.	100	3	94	3850.	580.

Table 4. (Continued)

CODE	DATE	TIME	FLOW L/MIN	VOLTAGE (%)	BANKS ON	LAMPS ON	TOTAL COLI COL/100	FECAL COLI COL/100
429-332-E1	02/02/83	1100	1665.	100	3	94	12654.	3450.
429-333-E1	02/02/83	1500	908.	100	3	94	260.	84.
430-334-E1	02/03/83	1200	397.	100	3	94	92.	13.
430-335-E1	02/03/83	1430	1665.	100	3	94	2322.	673.
455-339-E1	02/28/83	1130	1116.	100	3	92	956.	255.
455-340-E1	02/28/83	1500	1835.	100	3	92	2630.	759.
477-360-E1	03/22/83	1200	1835.	100	2	58	16820.	7490.
477-361-E1	03/22/83	1500	2952.	100	2	58	52500.	19900.
478-362-E1	03/23/83	1430	2952.	100	2	58	18650.	9490.
478-363-E1	03/24/83	1100	1513.	100	2	58	540.	240.
483-364-E1	03/28/83	1130	2584.	100	2	58	8410.	1770.
483-365-E1	03/28/83	1500	1249.	100	2	58	365.	80.
484-366-E1	03/29/83	1130	2763.	100	3	98	1250.	460.
484-367-E1	03/29/83	1500	813.	100	2	58	155.	70.
497-369-E1	04/11/83		2573.	100	2	58	4600.	930.
497-370-E1	04/11/83		946.	100	2	58	220.	72.
497-371-E1	04/12/83	1030	2573.	100	2	58	9240.	2750.
498-372-E1	04/12/83	1300	1797.	100	2	58	3150.	1170.
499-374-E1	04/13/83		1797.	100	2	58	2100.	950.
499-375-E1	04/13/83		2573.	100	2	58	1120.	310.
499-376-E1	04/13/83		946.	100	2	58	180.	60.
504-383-E1	04/18/83	1300	2573.	100	2	58	5180.	1340.
504-384-E1	04/18/83	1500	946.	100	2	58	550.	200.
504-385-E1	04/18/83	1700	1797.	100	2	58	1990.	510.
505-386-E1	04/19/83	1200	946.	100	2	58	1032.	390.
505-387-E1	04/19/83	1400	1797.	100	2	58	15320.	7990.
505-388-E1	04/19/83	1600	2573.	100	2	58	23000.	13320.
506-389-E1	04/20/83		1797.	100	2	58	2010.	1150.
506-390-E1	04/20/83		2573.	100	2	58	1640.	680.
506-391-E1	04/20/83		946.	100	2	58	1370.	270.
507-395-E1	04/21/83	1200	1797.	100	2	56	5987.	2316.
507-396-E1	04/21/83	1315	946.	100	2	56	842.	330.
507-397-E1	04/21/83	1500	2573.	100	2	56	39000.	16879.
514-407-E1	04/28/83	1100	946.	100	2	56	5800.	1900.
514-408-E1	04/28/83	1300	1797.	100	2	56	2370.	950.
514-409-E1	04/28/83	1500	2573.	100	2	56	2720.	660.
520-411-E1	05/04/83	1300	2573.	100	2	56	29100.	10160.
520-412-E1	05/04/83	1530	1797.	100	2	56	**********	16140.
521-413-E1	05/05/83	1200	2573.	100	2	56	35000.	14200.
521-414-E1	05/05/83	1330	1797.	100	2	56	88000.	25500.
521-415-E1	05/05/83	1500	946.	100	2	56	28750.	12850.
589-428-E1	07/18/83	1100	775.	100	1	40	180.	80.
589-430-E1	07/12/83	1515	2271.	100	1	40	3700.	1400.
590-431-E1	07/13/83	1100	775.	100	1	40	140.	90.
590-432-E1	07/13/83	1315	1703.	100	1	40	1530.	635.
590-433-E1	07/13/83	1530	2271.	100	1	40	7500.	4150.
591-434-E1	07/14/83		775.	100	1	40	370.	96.
591-435-E1	07/14/83		1703.	100	1	40	2460.	865.

Table 4. (Continued)

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*  CODE     * *   DATE    *  *TIME*  *  FLOW   *  *VOLTAGE*  *BANKS*  *LAMPS*  * TOTAL  *  * FECAL  *
*           * *           *  *     *  *  L/MIN*  *   (%)   *  * ON   *  *   ON *  *  COLI  *  *  COLI  *
*           * *           *  *     *  *        *  *         *  *      *  *      *  *COL/100*  *COL/100*

591-436-E1    07/14/83              2271.          100          1         40      7230.        2065.
595-437-E1    07/19/83     1000     2573.          100          2         58       630.         230.
595-439-E1    07/19/83     1500      170.          100          2         58       445.          70.
609-455-E1    08/01/83     1130     1627.          100          2         58       480.         230.
609-456-E1    08/01/83     1400      813.          100          2         58       170.          43.
610-457-E1    08/02/83     0930      813.          100          2         58        21.           8.
610-458-E1    08/02/83     1115     1627.          100          2         58       600.         160.
610-459-E1    08/02/83     1500     2460.          100          2         58      1270.         630.
611-461-E1    08/03/83     1230     2460.          100          2         58      2620.         920.
611-462-E1    08/03/83     1500      813.          100          2         58        43.          14.
612-463-E1    08/04/83     0945      813.          100          2         58       110.          33.
612-464-E1    08/04/83     1330     2460.          100          2         58     18300.        6230.
616-466-E1    08/08/83     0935     2365.          100          2         58       670.         450.
616-467-E1    08/08/83     1145     1835.          100          2         58       300.          60.
616-468-E1    08/09/83     1500     1116.          100          2         58        70.          17.
617-469-E1    08/09/83     0945     1835.          100          2         58        73.   ***********
617-470-E1    08/09/83     1200     1116.          100          2         58        12.   ***********
617-471-E1    08/09/83     1500     2365.          100          2         58       870.         280.
618-472-E1    08/10/83     1000     1116.          100          2         58        14.           6.
618-473-E1    08/10/83     1200     1835.          100          2         58        67.          33.
619-475-E1    08/11/83     0925     2365.          100          2         58       355.         145.
619-476-E1    08/11/83     1130     1835.          100          2         58       540.         260.
619-477-E1    08/11/83     1430     1116.          100          2         58       230.          85.
633-484-E1    08/25/83     1000     1116.          100          2         58       305.         180.
633-485-E1    08/25/83     1330     1835.          100          2         58      4250.        1300.
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Table 4. (Continued)

CODE DAY NO	DATE	TIME	WIPER RATE (CPH)	LAMP TEMP (C)	LAMPS ON	VOLTAGE (%)	I METER A (%)	I METER B (%)	I METER C (%)	IL 570 INF W/CM2	IL 570 EFF W/CM2
002	12/02/81	0900	****	****	92	90	****	****	****	0.00E 00	0.00E 00
003	12/03/81	0800	****	****	92	90	****	****	****	0.00E 00	0.00E 00
007	12/07/81	0930	6.	****	91	90	****	****	****	0.00E 00	0.00E 00
014	12/14/81	1415	6.	****	100	90	42.	32.	36.	0.00E 00	0.00E 00
015	12/15/81	1000	6.	****	100	90	38.	32.	32.	0.00E 00	0.00E 00
016	12/16/81	1000	6.	****	100	90	36.	30.	34.	0.00E 00	0.00E 00
017	12/17/81	0800	6.	****	100	90	36.	32.	34.	0.00E 00	0.00E 00
021	12/21/81	0930	****	****	100	90	36.	32.	36.	0.00E 00	0.00E 00
023	12/23/81	1000	6.	****	99	90	40.	36.	38.	0.00E 00	0.00E 00
028	12/28/81	0800	6.	****	100	90	36.	34.	36.	0.00E 00	0.00E 00
029	12/29/81	0830	6.	****	100	90	38.	34.	40.	0.00E 00	0.00E 00
035	01/04/82	0930	****	****	0	0	****	****	****	0.00E 00	0.00E 00
037	01/06/82	0700	****	****	100	90	38.	35.	36.	0.00E 00	0.00E 00
038	01/07/82	0630	6.	****	100	90	34.	32.	36.	0.00E 00	0.00E 00
041	01/11/82	1315	6.	****	98	90	36.	31.	33.	0.00E 00	0.00E 00
042	01/12/82	0930	6.	****	97	90	36.	30.	32.	0.00E 00	0.00E 00
051	01/20/82	0930	6.	****	96	90	38.	35.	39.	0.00E 00	0.00E 00
058	01/27/82	0900	6.	****	96	90	****	****	****	0.00E 00	0.00E 00
059	01/28/82	1000	6.	****	96	90	36.	32.	38.	0.00E 00	0.00E 00
066	02/04/82	0930	6.	****	99	90	0.	52.	50.	0.00E 00	0.00E 00
071	02/09/82	1100	6.	22.7	98	90	****	10.	0.	0.00E 00	0.00E 00
072	02/10/82	0900	6.	21.6	98	90	****	104.	****	0.00E 00	0.00E 00
073	02/11/82	1030	6.	22.2	98	90	****	100.	****	0.00E 00	0.00E 00
078	02/16/82	1100	6.	22.2	97	90	****	92.	****	0.00E 00	0.00E 00
079	02/17/82	0930	6.	25.3	97	90	****	106.	****	0.00E 00	0.00E 00
086	02/24/82	0930	6.	****	96	90	0.	48.	55.	0.90E-05	0.22E-04
087	02/25/82	0930	6.	****	96	90	0.	45.	52.	0.18E-04	0.53E-04
091	03/01/82	1330	12.	****	92	90	0.	44.	56.	0.16E-03	0.28E-03
092	03/02/82	1000	****	****	0	0	****	****	****	0.00E 00	0.00E 00
093	03/03/82	1015	****	****	0	0	****	****	****	0.00E 00	0.00E 00
094	03/04/82	1015	****	****	0	0	****	****	****	0.00E 00	0.00E 00
098	03/08/82	1415	****	****	0	0	****	****	****	0.00E 00	0.00E 00
099	03/09/82	0930	****	****	0	0	****	****	****	0.00E 00	0.00E 00
100	03/10/82	1100	12.	****	84	90	****	****	****	0.42E-04	0.57E-04
105	03/15/82	1330	12.	****	81	100	0.	18.	22.	0.21E-03	0.37E-03
106	03/16/82	1130	12.	****	81	100	0.	20.	24.	0.48E-04	0.77E-04
107	03/17/82	1315	6.	****	82	100	20.	17.	24.	0.62E-04	0.16E-03
149	04/28/82	1115	****	****	0	0	****	****	****	0.00E 00	0.00E 00
150	04/29/82	1100	****	****	0	0	****	****	****	0.00E 00	0.00E 00
154	05/03/82	1330	6.	****	95	100	****	****	****	0.10E-03	0.24E-03
155	05/04/82	1130	6.	****	95	100	****	****	****	0.30E-04	0.10E-03
156	05/05/82	1400	****	****	0	0	****	****	****	0.00E 00	0.00E 00
157	05/06/82	1430	****	****	0	0	****	****	****	0.00E 00	0.00E 00
161	05/10/82	1400	6.	****	0	0	****	****	****	0.00E 00	0.00E 00
162	05/11/82		****	****	0	0	****	****	****	0.00E 00	0.00E 00
168	05/17/82		6.	****	95	100	****	****	****	0.00E 00	0.00E 00
169	05/18/82	1045	6.	****	95	100	****	****	****	0.00E 00	0.00E 00

Table 5. Unit 2 (Closely Spaced Quartz System) Operating Conditions

CODE DAY NO	DATE	TIME	WIPER RATE (CPH)	LAMP TEMP (C)	LAMPS ON	VOLTAGE (%)	I METER A (%)	I METER B (%)	I METER C (%)	IL 570 INF W/CM2	IL 570 EFF W/CM2
171	05/20/82	1015	6.	****	89	100	****	****	****	0.00E 00	0.00E 00
176	05/25/82		1.	****	100	100	****	****	****	0.31E-03	0.44E-03
177	05/26/82	1000	1.	****	100	100	****	****	****	0.35E-03	0.46E-03
183	06/01/82	1000	1.	****	74	100	****	****	****	0.33E-03	0.38E-03
196	06/14/82		1.	****	96	100	****	****	****	0.43E-03	0.53E-03
197	06/15/82		****	****	0	0	****	****	****	0.00E 00	0.00E 00
198	06/16/82		1.	****	96	0	****	****	****	0.67E-03	0.78E-03
203	06/21/82	1100	1.	****	91	100	****	****	****	0.50E-03	0.80E-03
204	06/22/82	1000	1.	****	95	100	****	****	****	0.48E-03	0.80E-03
205	06/23/82	1000	1.	****	94	100	****	****	****	0.29E-03	0.47E-03
210	06/28/82	0930	1.	****	95	100	****	****	****	0.72E-03	0.11E-02
211	06/29/82	0800	1.	****	95	100	****	****	****	0.40E-03	0.53E-03
212	06/30/82	0800	1.	****	94	100	****	****	****	0.28E-03	0.40E-03
218	07/06/82	0830	1.	****	94	100	****	****	****	0.54E-03	0.91E-03
219	07/07/82		1.	****	94	100	****	****	****	0.00E 00	0.00E 00
225	07/13/82	0830	1.	****	90	90	****	****	****	0.30E-03	0.45E-03
226	07/14/82	0930	1.	****	90	100	****	****	****	0.52E-03	0.11E-02
231	07/19/82	0900	1.	****	90	100	****	****	****	0.64E-03	0.34E-03
239	07/27/82	0830	1.	****	84	100	****	****	****	0.25E-03	0.00E 00
240	07/28/82	0830	1.	****	84	100	****	****	****	0.00E 00	0.29E-03
241	07/29/82	0800	1.	****	84	100	****	****	****	0.57E-03	0.00E 00
245	08/02/82	0830	1.	****	84	100	****	****	****	0.48E-03	0.00E 00
246	08/03/82	0800	1.	****	84	100	****	****	****	0.00E 00	0.00E 00
247	08/04/82	0800	1.	****	84	100	****	****	****	0.00E 00	0.00E 00
252	08/09/82	0830	1.	****	76	100	****	****	****	0.91E-03	0.00E 00
253	08/10/82	0730	1.	****	74	100	****	****	****	0.19E-03	0.00E 00
254	08/11/82	0900	1.	****	74	100	****	****	****	0.30E-03	0.00E 00
260	08/17/82	1015	1.	****	94	100	****	****	****	0.00E 00	0.00E 00
266	08/23/82	0850	****	****	0	0	****	****	****	0.00E 00	0.00E 00
267	08/24/82	0800	****	****	0	0	****	****	****	0.00E 00	0.00E 00
268	08/25/82	0750	****	****	0	0	****	****	****	0.00E 00	0.00E 00
274	08/31/82		****	****	0	0	****	****	****	0.00E 00	0.00E 00
275	09/01/82	1530	1.	****	76	100	****	****	****	0.00E 00	0.00E 00
281	09/07/82	0930	****	****	0	0	****	****	****	0.00E 00	0.00E 00
282	09/08/82	1130	****	****	0	0	****	****	****	0.00E 00	0.00E 00
296	09/22/82	1200	****	****	0	0	****	****	****	0.00E 00	0.00E 00
308	10/04/82	1200	1.	****	100	100	****	****	****	0.40E-03	0.57E-03
309	10/05/82	1000	1.	****	96	100	****	****	****	0.22E-03	0.23E-03
310	10/06/82	1015	1.	****	96	100	****	****	****	0.26E-03	0.30E-03
315	10/12/82	1430	1.	****	94	100	****	****	****	0.45E-03	0.33E-03
316	10/13/82	1100	1.	****	94	100	****	****	****	0.00E 00	0.60E-06
321	10/18/82	1200	1.	****	94	100	****	****	****	0.26E-03	0.50E-03
322	10/19/82	1000	1.	****	94	100	****	****	****	0.95E-04	0.21E-03
329	10/25/82	1610	1.	****	88	100	****	****	****	0.50E-03	0.17E-04
330	10/26/82	1215	1.	****	88	100	****	****	****	0.27E-03	0.00E 00
331	10/27/82	1130	1.	****	88	100	****	****	****	0.15E-03	0.00E 00
337	11/02/82	1000	1.	****	88	100	****	****	****	0.40E-04	0.00E 00

Table 5. (Continued)

CODE DAY NO	DATE	TIME	WIPER RATE (CPH)	LAMP TEMP (C)	LAMPS ON	VOLTAGE (%)	I METER A (%)	I METER B (%)	I METER C (%)	IL 570 INF W/CM2	IL 570 EFF W/CM2
338	11/03/82	1000	1.	****	90	100	****	****	****	0.88E-04	0.00E 00
343	11/08/82	1300	1.	****	90	100	****	****	****	0.00E 00	0.00E 00
345	11/10/82	1000	1.	****	90	100	****	****	****	0.00E 00	0.16E-03
350	11/15/82	1130	****	****	52	100	****	****	****	0.00E 00	0.42E-03
351	11/16/82	1030	****	****	52	100	****	****	****	0.00E 00	0.43E-03
352	11/17/82	1130	****	****	52	100	****	****	****	0.00E 00	0.68E-04
353	11/18/82	1145	****	****	52	100	****	****	****	0.00E 00	0.60E-04
357	11/22/82	1430	****	****	52	100	****	****	****	0.00E 00	0.90E-04
358	11/23/82	1100	****	****	52	100	****	****	****	0.00E 00	0.14E-04
364	11/29/82	1100	****	****	90	100	****	****	****	0.00E 00	0.11E-03
365	11/30/82	1300	****	****	90	100	****	****	****	0.00E 00	0.70E-04
366	12/01/82	1145	****	****	90	100	****	****	****	0.00E 00	0.24E-04
367	12/02/82	1200	****	****	90	100	****	****	****	0.00E 00	0.60E-04
371	12/06/82	1200	****	****	90	100	****	****	****	0.00E 00	0.80E-04
372	12/07/82	1130	****	****	90	100	****	****	****	0.00E 00	0.20E-04
373	12/08/82	1130	****	****	90	100	****	****	****	0.00E 00	0.22E-04
378	12/13/82	1200	****	****	90	100	****	****	****	0.00E 00	0.76E-04
379	12/14/82	1130	****	****	90	100	****	****	****	0.00E 00	0.29E-04
380	12/15/82	1430	1.	****	100	100	****	****	****	0.00E 00	0.66E-04
381	12/16/82	1200	1.	****	100	100	****	****	****	0.00E 00	0.00E 00
385	12/20/82	1130	1.	****	100	100	****	****	****	0.00E 00	0.00E 00
386	12/21/82	1115	1.	****	100	100	****	****	****	0.00E 00	0.C0E 00
399	01/03/83	1230	1.	****	100	100	****	****	****	0.00E 00	0.00E 00
400	01/04/83	1030	****	****	100	100	****	****	****	0.00E 00	0.00E 00
401	01/05/83	1145	****	****	100	100	****	****	****	0.00E 00	0.00E 00
402	01/06/83	1030	****	****	100	100	****	****	****	0.00E 00	0.00E 00
406	01/10/83	1330	****	****	100	100	****	****	****	0.00E 00	0.18E-03
407	01/11/83	1200	****	****	100	100	****	****	****	0.00E 00	0.19E-03
408	01/12/83	1045	****	****	100	100	****	****	****	0.00E 00	0.30E-03
409	01/13/83	1145	1.	****	100	100	****	****	****	0.00E 00	0.14E-04
413	01/17/83	1500	1.	****	100	100	****	****	****	0.00E 00	0.27E-03
414	01/18/83	1030	1.	****	100	100	****	****	****	0.00E 00	0.55E-04
415	01/19/83	1200	1.	****	100	100	****	****	****	0.00E 00	0.20E-04
416	01/20/83	1200	1.	****	100	100	****	****	****	0.00E 00	0.83E-04
420	01/24/83	1245	1.	****	100	100	****	****	****	0.00E 00	0.10E-03
421	01/25/83	1100	1.	****	100	100	****	****	****	0.00E 00	0.13E-03
422	01/26/83	1200	1.	****	100	100	****	****	****	0.00E 00	0.00E 00
423	01/27/83	1200	1.	****	100	100	****	****	****	0.00E 00	0.00E 00
427	01/31/83	1130	1.	****	100	100	****	****	****	0.00E 00	0.00E 00
428	02/01/83		1.	****	100	100	****	****	****	0.00E 00	0.00E 00
429	02/02/83		1.	****	100	100	****	****	****	0.00E 00	0.00E 00
430	02/03/83		1.	****	100	100	****	****	****	0.00E 00	0.00E 00
441	02/14/83	1230	1.	****	100	100	****	****	****	0.00E 00	0.00E 00
444	02/17/83	1130	1.	****	100	100	****	****	****	0.00E 00	0.00E 00
455	02/28/83	1100	1.	****	100	100	****	****	****	0.00E 00	0.21E-03
462	03/07/83	1100	1.	****	100	100	****	****	****	0.00E 00	0.25E-03
463	03/08/83	1100	1.	****	100	100	****	****	****	0.00E 00	0.22E-03

Table 5. (Continued)

CODE DAY NO	DATE	TIME	WIPER RATE (CPH)	LAMP TEMP (C)	LAMPS ON	VOLTAGE (%)	I METER A (%)	I METER B (%)	I METER C (%)	IL 570 INF W/CM2	IL 570 EFF W/CM2
464	03/09/83	1100	1.	****	100	100	****	****	****	0.00E 00	0.20E-03
469	03/14/83	1145	1.	****	100	100	****	****	****	0.00E 00	0.40E-03
470	03/15/83	0900	1.	****	100	100	****	****	****	0.00E 00	0.33E-03
471	03/16/83	0900	1.	****	100	100	****	****	****	0.00E 00	0.00E 00
472	03/17/83	1100	1.	****	98	100	****	****	****	0.00E 00	0.20E-03
476	03/21/83	1130	1.	****	98	100	****	****	****	0.00E 00	0.10E-04
477	03/22/83	1130	1.	****	98	100	****	****	****	0.00E 00	0.24E-03
478	03/28/83	1415	1.	****	98	100	****	****	****	0.00E 00	0.21E-03
479	03/24/83	1045	1.	****	98	100	****	****	****	0.00E 00	0.14E-03
483	03/28/83	1030	1.	****	98	100	****	****	****	0.00E 00	0.53E-03
484	03/28/83	0900	1.	****	98	100	****	****	****	0.00E 00	0.22E-03
497	04/11/83	1300	1.	****	98	100	****	****	****	0.00E 00	0.49E-03
498	04/12/83	1000	1.	****	98	100	****	****	****	0.00E 00	0.44E-03
499	04/13/83	1115	1.	****	98	100	****	****	****	0.00E 00	0.48E-03
500	04/14/83		****	****	0	0	****	****	****	0.00E 00	0.00E 00
504	04/18/83	1200	1.	****	98	100	****	****	****	0.00E 00	0.36E-03
505	04/19/83	1030	1.	****	98	100	****	****	****	0.00E 00	0.38E-03
506	04/20/83	1000	1.	****	98	100	****	****	****	0.00E 00	0.46E-03
507	04/21/83	1145	1.	****	96	100	****	****	****	0.00E 00	0.29E-03
511	04/25/83	1000	****	****	0	0	****	****	****	0.00E 00	0.00E 00
512	04/26/83	1000	****	****	0	0	****	****	****	0.00E 00	0.00E 00
513	04/27/83	0930	****	****	0	0	****	****	****	0.00E 00	0.00E 00
514	04/28/83	0900	1.	****	96	100	****	****	****	0.00E 00	0.00E 00
520	05/04/83	1115	1.	****	96	100	****	****	****	0.00E 00	0.00E 00
521	05/05/83	1130	1.	****	96	100	****	****	****	0.00E 00	0.00E 00
574	06/27/83	0900	1.	****	0	0	****	****	****	0.00E 00	0.00E 00
575	06/28/83	0900	****	****	0	0	****	****	****	0.00E 00	0.00E 00
576	06/29/83	0830	****	****	0	0	****	****	****	0.00E 00	0.00E 00
577	06/30/83	1100	****	****	0	0	****	****	****	0.00E 00	0.00E 00
589	07/12/83	1000	1.	****	38	100	****	****	****	0.00E 00	0.00E 00
590	07/13/83	1030	1.	****	38	100	****	****	****	0.51E-03	0.00E 00
591	07/13/83	1030	1.	****	38	100	****	****	****	0.90E-03	0.00E 00
595	07/18/83	1000	1.	****	58	100	****	****	****	0.20E-02	0.00E 00
596	07/19/83	1013	1.	****	58	100	****	****	****	0.60E-04	0.00E 00
597	07/20/83	1045	1.	****	58	100	****	****	****	0.17E-04	0.00E 00
602	07/25/83	1030	1.	****	56	100	****	****	****	0.98E-04	0.00E 00
603	07/26/83	0915	1.	****	54	100	****	****	****	0.85E-04	0.00E 00
604	07/27/83	0845	1.	****	54	100	****	****	****	0.17E-03	0.00E 00
605	07/25/83	1030	1.	****	54	100	****	****	****	0.16E-04	0.00E 00
609	08/01/83	0915	1.	****	54	100	****	****	****	0.40E-03	0.00E 00
610	08/02/83	0905	1.	****	54	100	****	****	****	0.34E-03	0.00E 00
611	08/03/83	0910	1.	****	54	100	****	****	****	0.00E 00	0.00E 00
612	08/04/83	0915	1.	****	54	100	****	****	****	0.18E-03	0.00E 00
616	08/08/83	0930	****	****	0	0	****	****	****	0.00E 00	0.00E 00
617	08/09/83	0930	****	****	0	0	****	****	****	0.00E 00	0.00E 00
618	08/10/83	0930	****	****	0	0	****	****	****	0.00E 00	0.00E 00
619	08/11/83	0910	1.	****	0	0	****	****	****	0.00E 00	0.00E 00

Table 5. (Continued)

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*   CODE    * *   DATE   *  *TIME*  *WIPER*  *LAMP*  *LAMPS*  *VOLTAGE*  *  I   *  *  I   *  *  I   *  * IL   *  * IL   *
*           * *          *  *    *  *RATE *  *TEMP*  * ON   *  *        *  *METER*  *METER*  *METER*  * 570  *  * 570  *
* DAY NO    * *          *  *    *  *(CPH)*  * (C)*  *      *  *        *  *  A   *  *  B   *  *  C   *  * INF  *  * EFF  *
*           * *          *  *    *  *     *  *    *  *      *  *  (%)   *  * (%)  *  * (%)  *  * (%)  *  *W/CM2*  *W/CM2*

    630        08/22/83     0900    ****      ****       0          0        ****      ****      ****    0.00E 00   0.00E 00
    631        08/23/83     1000    ****      ****       0          0        ****      ****      ****    0.00E 00   0.00E 00
    632        08/24/83             ****      ****       0          0        ****      ****      ****    0.00E 00   0.00E 00
    633        08/25/83     1200    ****      ****       0          0        ****      ****      ****    0.00E 00   0.00E 00
    637        08/29/83     1030    ****      ****       0          0        ****      ****      ****    0.00E 00   0.00E 00
    638        08/30/83     1115    ****      ****       0          0        ****      ****      ****    0.00E 00   0.00E 00
    639        08/31/83     1130      1.      ****      48        100        ****      ****      ****    0.12E-04   0.00E 00
    640        09/01/83     1100      1.      ****      56        100        ****      ****      ****    0.57E-04   0.00E 00
    645        09/06/83     1130      1.      ****      44        100        ****      ****      ****    0.20E-04   0.00E 00
    646        09/07/83     1030      1.      ****      56        100        ****      ****      ****    0.19E-04   0.00E 00
    647        09/08/83     1100      1.      ****      56        100        ****      ****      ****    0.30E-04   0.00E 00
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Table 5. (Continued)

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*   CODE     * *   DATE    *  *TIME*  *   FLOW  *  *VOLTAGE*  *BANKS*  *LAMPS*  * TOTAL  *  * FECAL  *
*            * *           *  *     *  *   L/MIN*  *   (%)   *  * ON   *  *  ON  *  *  COLI  *  *  COLI  *
*            * *           *  *     *  *        *  *         *  *      *  *      *  *COL/100*  *COL/100*

002-001-E2     12/02/81     0830      1638.        90          3         92        2100.  ***********
002-002-E2     12/02/81     1045      1014.        90          3         92         390.  ***********
002-003-E2     12/02/81     1200       382.        90          3         92          44.  ***********
002-004-E2     12/02/81     1430      2482.        90          3         92         200.  ***********
003-005-E2     12/03/81     0830      1014.        90          3        100        2400.  ***********
003-006-E2     12/03/81     1045      2482.        90          3         92       20400.  ***********
003-007-E2     12/03/81     1130      1638.        90          3         91         710.  ***********
003-008-E2     12/03/81     1300       382.        90          3         91          32.  ***********
007-009-E2     12/07/81     0930       382.        90          3         91          32.  ***********
014-012-E2     12/14/81     0800       246.        90          3        100          30.  ***********
014-013-E2     12/14/81     1130      1423.        90          3        100        5000.         126.
014-014-E2     12/14/81     1415      2036.        90          3        100        5700.         315.
015-015-E2     12/15/81     1030       382.        90          3        100         255.  ***********
016-019-E2     12/16/81     1230      1014.        90          3         99          36.           8.
021-023-E2     12/21/81     0930       382.        90          3        100          86.          20.
021-024-E2     12/21/81     1130      1014.        90          3        100         640.         315.
023-026-E2     12/23/81     1000      2501.        90          3         99       40000.        2830.
023-027-E2     12/23/81     1130      1638.        90          3         99        8200.         880.
023-028-E2     12/23/81     1330      1014.        90          3         99        2100.         360.
028-029-E2     12/28/81     0830       465.        90          3        100        2240.         160.
028-031-E2     12/28/81     1230      1956.        90          3         90        1400.        2100.
029-033-E2     12/29/81     1130       329.        90          3        100          90.          24.
029-034-E2     12/29/81     1330      1014.        90          3        100        3000.  ***********
037-039-E2     01/06/82     0700      1040.        90          3        100        1400.         270.
037-040-E2     01/06/82     0930      1638.        90          3        100        6900.        1260.
037-041-E2     01/06/82     1200       363.        90          3        100         240.          13.
038-042-E2     01/07/82     0700       363.        90          3        100  ***********          23.
038-043-E2     01/07/82     1200       382.        90          3        100         465.          28.
041-044-E2     01/11/82     1345      2713.        90          3         99       27500.        3800.
042-045-E2     01/12/82     0945       397.        90          3         97         240.          12.
042-046-E2     01/12/82     1115       965.        90          3         97        1240.         155.
042-047-E2     01/12/82     1400      1638.        90          3         97        4000.        1140.
051-048-E2     01/20/82     1015      1040.        90          3         96  ***********        6800.
051-049-E2     01/20/82     1145      2482.        90          3         96  ***********       48500.
057-050-E2     01/20/82     1315       382.        90          3         96        1760.         700.
058-051-E2     01/27/82     0945       344.        90          3         96          18.          16.
058-052-E2     01/27/82     1145       987.        90          3         96         560.         280.
058-053-E2     01/27/82     1315      1638.        90          3         96        5300.        1580.
059-054-E2     01/28/82     1000      2535.        90          3         96       18500.        2200.
059-055-E2     01/28/82     1145      1604.        90          3         96        4600.        1200.
059-056-E2     01/28/82     1330      1014.        90          3         96         760.         340.
066-057-E2     02/04/82     1000       382.        90          3         99          46.          32.
066-058-E2     02/04/82     1330      1294.        90          3        100        2900.         295.
169-122-E2     05/18/82     1330      1294.       100          3         95         215.          68.
171-123-E2     05/20/82     1030       556.       100          3         89          76.          64.
176-124-E2     05/25/82     1000       821.       100          3        100         100.          32.
176-125-E2     05/25/82     1230      1294.       100          3        100          77.          18.
176-126-E2     05/25/82     1500      2573.       100          3        100         700.          90.
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Table 6. Unit 2 (Closely Spaced Quartz System) Effluent - Secondary

CODE	DATE	TIME	FLOW L/MIN	VOLTAGE (%)	BANKS ON	LAMPS ON	TOTAL COLI COL/100	FECAL COLI COL/100
177-127-E2	05/26/82	1000	1294.	100	3	100	26.	2.
177-128-E2	05/26/82	1200	821.	100	3	100	21.	7.
177-129-E2	05/26/82	1500	2392.	100	3	100	500.	225.
183-130-E2	06/01/82	1000	821.	100	3	74	165.	53.
183-131-E2	06/01/82	1230	1294.	100	3	74	46.	26.
196-133-E2	06/14/82		2392.	100	3	96	498.	95.
196-135-E2	06/14/82		1294.	100	3	96	71.	55.
203-142-E2	06/21/82	1130	821.	100	3	91	8.	2.
203-143-E2	06/21/82	1345	1294.	100	3	91	24.	14.
203-144-E2	06/21/82	1600	2573.	100	3	91	50.	15.
204-145-E2	06/22/82	1030	1294.	100	3	95	24.	20.
204-146-E2	06/22/82	1315	2573.	100	3	95	18.	12.
204-147-E2	06/22/82	1600	821.	100	3	95	4.	4.
205-148-E2	06/23/82	1015	1294.	100	3	94	4.	2.
205-149-E2	06/23/82	1230	821.	100	3	94	8.	1.
205-150-E2	06/23/82	1500	2573.	100	3	94	980.	600.
210-151-E2	06/28/82	0930	1294.	100	3	95	14.	9.
210-152-E2	06/28/82	1100	2573.	100	3	95	52.	32.
211-154-E2	06/29/82	0815	821.	100	3	95	4.	1.
211-155-E2	06/29/82	1115	1294.	100	3	95	10.	3.
211-156-E2	06/29/82	1330	2573.	100	3	95	58.	26.
212-157-E2	06/30/82	0830	2573.	100	3	94	108.	45.
212-158-E2	06/30/82	1100	1294.	100	3	94	44.	32.
212-159-E2	06/30/82	1330	775.	100	3	94	6.	3.
218-160-E2	07/06/82	0900	821.	100	3	94	12.	1.
218-161-E2	07/06/82	1115	1294.	100	3	94	26.	2.
218-162-E2	07/06/82	1330	2573.	100	3	94	***********	35.
219-163-E2	07/07/82	1200	1294.	100	2	60	140.	92.
225-164-E2	07/13/82	0900	1423.	100	2	60	97.	66.
225-165-E2	07/13/82		1014.	100	2	60	57.	29.
225-166-E2	07/13/82		2573.	100	2	60	1810.	170.
226-167-E2	07/14/82	0900	2573.	100	2	60	333.	40.
226-168-E2	07/14/82	1130	1423.	100	2	60	230.	20.
231-170-E2	07/19/82		1423.	100	2	60	50.	12.
231-171-E2	07/19/82		2573.	100	2	60	195.	65.
231-172-E2	07/19/82		1014.	100	2	60	30.	8.
239-173-E2	07/27/82	0900	1014.	100	2	58	36.	25.
239-175-E2	07/27/82	1400	2573.	100	2	58	910.	183.
240-178-E2	07/28/82	1415	1423.	100	2	58	178.	82.
241-179-E2	07/29/82	0930	1014.	100	2	58	30.	17.
245-180-E2	08/02/82	0900	1423.	100	2	58	26.	6.
245-181-E2	08/02/82	1100	2573.	100	2	58	40.	25.
246-183-E2	08/03/82	0900	1423.	100	2	58	46.	11.
246-184-E2	08/03/82	1115	1014.	100	2	58	62.	10.
246-185-E2	08/03/82	1330	2573.	100	2	58	2100.	620.
247-186-E2	08/04/82	0900	1423.	100	2	58	124.	34.
247-187-E2	08/04/82	1130	2573.	100	2	58	1500.	500.
252-189-E2	08/09/82	0900	1014.	100	2	57	26.	21.

Table 6. (Continued)

CODE	DATE	TIME	FLOW L/MIN	VOLTAGE (%)	BANKS ON	LAMPS ON	TOTAL COLI COL/100	FECAL COLI COL/100
252-190-E2	08/09/82	1130	1423.	100	2	57	70.	25.
252-191-E2	08/09/82	1430	2573.	100	2	57	370.	74.
253-192-E2	08/10/82	0900	1014.	100	2	57	***********	134.
253-193-E2	08/10/82	1130	1423.	100	2	57	***********	570.
253-194-E2	08/10/82	1330	2573.	100	2	57	***********	4500.
254-195-E2	08/11/82	1015	2573.	100	2	57	***********	265.
254-196-E2	08/11/82	1200	1423.	100	2	57	***********	51.
254-197-E2	08/11/82	1400	1014.	100	2	57	***********	35.
300-219-E2	10/04/82	1330	325.	100	3	100	15.	***********
308-220-E2	10/04/82	1600	2482.	100	3	100	128.	120.
309-221-E2	10/05/82		1014.	100	3	96	***********	44.
309-222-E2	10/05/82		382.	100	3	96	***********	10.
310-223-E2	10/06/82	1100	2482.	100	3	96	***********	48.
310-224-E2	10/06/82	1400	1014.	100	3	96	***********	24.
268-225-E2	10/12/82	113	1192.	100	3	94	10.	6.
315-226-E2	10/12/82	1515	2573.	100	3	94	80.	***********
321-229-E2	10/18/82	140	1014.	100	3	94	120.	66.
322-232-E2	10/19/82		1014.	100	3	94	1300.	340.
322-233-E2	10/19/82		2573.	100	3	94	4850.	910.
330-237-E2	10/26/82		1014.	100	3	88	40.	24.
331-238-E2	10/27/82	1130	2573.	100	3	88	980.	395.
331-239-E2	10/27/82	1330	1014.	100	3	88	82.	49.
428-329-E2	02/01/83	1100	908.	100	3	100	538.	250.
428-330-E2	02/01/83	1330	473.	100	3	100	150.	70.
428-331-E2	02/01/83	1700	1835.	100	3	100	7200.	890.
429-332-E2	02/02/83	1100	1665.	100	3	100	2503.	825.
429-333-E2	02/02/83	1500	908.	100	3	100	210.	66.
430-334-E2	02/03/83	1200	397.	100	3	100	26.	18.
430-335-E2	02/03/83	1430	1665.	100	3	100	825.	277.
441-336-E2	02/14/83	1300	473.	100	3	100	32.	9.
444-337-E2	02/17/83	1300	1116.	100	3	100	1336.	549.
444-338-E2	02/17/83	1600	1835.	100	3	100	2389.	500.
455-339-E2	02/28/83	1130	1116.	100	3	100	1122.	225.
455-340-E2	02/28/83	1500	1835.	100	3	100	825.	216.
462-341-E2	03/07/83	1100	1021.	100	3	100	7050.	1485.
462-342-E2	03/07/83	1230	1646.	100	3	100	3350.	1170.
462-343-E2	03/07/83	1430	605.	100	3	100	23.	9.
463-344-E2	03/08/83	1115	775.	100	3	100	77.	30.
463-345-E2	03/08/83	1230	1835.	100	3	100	240.	117.
464-347-E2	03/09/83		1646.	100	3	100	550.	220.
464-348-E2	03/09/83		908.	100	3	100	295.	198.
464-349-E2	03/09/83		473.	100	3	100	145.	116.
469-350-E2	03/14/83	1200	1495.	100	3	100	860.	207.
469-351-E2	03/14/83	1400	548.	100	3	100	129.	53.
470-352-E2	03/15/83		1646.	100	3	100	370.	208.
470-353-E2	03/15/83		473.	100	3	100	40.	27.
472-356-E2	03/17/83	1130	416.	100	3	98	27.	13.
472-357-E2	03/17/83	150	813.	100	3	98	29.	25.

Table 6. (Continued)

CODE	DATE	TIME	FLOW L/MIN	VOLTAGE (%)	BANKS ON	LAMPS ON	TOTAL COLI COL/100	FECAL COLI COL/100
477-360-E2	03/22/83	1200	1835.	100	2	58	5660.	3000.
477-361-E2	03/22/83	1500	2384.	100	2	58	7140.	3200.
478-362-E2	03/23/83	1430	2573.	100	2	58	19300.	11500.
478-363-E2	03/24/83	1100	1513.	100	2	58	5400.	700.
483-364-E2	03/28/83	1130	1873.	100	2	58	1085.	570.
483-365-E2	03/28/83	1500	813.	100	2	58	400.	80.
484-366-E2	03/29/83	1130	2422.	100	3	98	2580.	1732.
484-367-E2	03/29/83	1500	813.	100	2	58	455.	160.
497-368-E2	04/11/83		1797.	100	2	58	1682.	850.
497-369-E2	04/11/83		2573.	100	2	58	11650.	4000.
497-370-E2	04/11/83		946.	100	2	58	3340.	480.
498-371-E2	04/12/83	1030	2573.	100	2	58	3800.	2280.
498-372-E2	04/12/83	1300	1797.	100	2	58	2600.	900.
498-373-E2	04/12/83	1600	946.	100	2	58	300.	75.
499-374-E2	04/13/83		1797.	100	2	58	2270.	780.
499-375-E2	04/13/83		2573.	100	2	58	4750.	1830.
499-376-E2	04/13/83		946.	100	2	58	275.	110.
504-383-E2	04/18/83	1300	2573.	100	2	58	5770.	2650.
504-384-E2	04/18/83	1500	946.	100	2	58	770.	440.
504-385-E2	04/18/83	1700	1797.	100	2	58	6930.	1690.
505-386-E2	04/19/83	1200	946.	100	2	58	3050.	1510.
505-387-E2	04/19/83	1400	1797.	100	2	58	31000.	15820.
505-388-E2	04/19/83	1600	2573.	100	2	58	36970.	16820.
506-389-E2	04/20/83		1797.	100	2	58	2800.	1320.
506-390-E2	04/20/83		2573.	100	2	58	5020.	1840.
506-391-E2	04/20/83		946.	100	2	58	730.	240.
507-395-E2	04/21/83	1200	1797.	100	2	56	8516.	4753.
507-396-E2	04/21/83	1315	946.	100	2	56	1665.	531.
507-397-E2	04/21/83	1500	2573.	100	2	56	28155.	9158.
514-407-E2	04/28/83	1100	946.	100	2	56	625.	190.
514-408-E2	04/28/83	1300	1797.	100	2	56	4750.	1050.
514-409-E2	04/28/83	1500	2573.	100	2	56	1350.	500.
520-410-E2	05/04/83	1100	946.	100	2	56	4750.	1230.
520-411-E2	05/04/83	1300	2573.	100	2	56	27600.	12160.
520-412-E2	05/04/83	1530	1797.	100	2	56	13490.	4300.
521-413-E2	05/05/83	1200	2573.	100	2	56	21300.	5670.
521-414-E2	05/05/83	1330	1797.	100	2	56	47500.	15800.
521-415-E2	05/05/83	1500	946.	100	2	56	10170.	4500.
589-428-E2	07/12/83	1100	775.	100	1	40	140.	200.
589-430-E2	07/12/83	1515	2271.	100	1	40	9990.	7990.
590-431-E2	07/13/83	1100	775.	100	1	38	220.	136.
590-432-E2	07/13/83	1315	1703.	100	1	38	7400.	4700.
590-433-E2	07/13/83	1530	2271.	100	1	38	**********	5900.
591-434-E2	07/14/83		775.	100	1	38	270.	60.
591-435-E2	07/14/83		1703.	100	1	38	6850.	3650.
591-436-E2	07/14/83		2271.	100	1	38	37000.	13510.
595-437-E2	07/18/83	1000	2573.	100	2	58	1200.	400.
609-454-E2	08/01/83	1000	2460.	100	2	54	5610.	3670.

Table 6. (Continued)

CODE	DATE	TIME	FLOW L/MIN	VOLTAGE (%)	BANKS ON	LAMPS ON	TOTAL COLI COL/100	FECAL COLI COL/100
609-455-E2	08/01/83	1130	1627.	100	2	54	2275.	2000.
609-456-E2	08/01/83	1400	813.	100	2	54	100.	53.
610-457-E2	08/02/83	0930	813.	100	2	54	21.	19.
610-458-E2	08/02/83	1115	1627.	100	2	54	2280.	600.
610-459-E2	08/02/83	1500	2460.	100	2	54	3180.	1050.
611-460-E2	08/03/83	0930	1627.	100	2	54	1030.	460.
611-461-E2	08/03/83	1230	2460.	100	2	54	6100.	2510.
611-462-E2	08/03/83	1500	613.	100	2	54	320.	38.
612-463-E2	08/04/83	0945	813.	100	2	54	60.	80.
612-464-E2	08/04/83	1330	2460.	100	2	54	22500.	7500.
612-465-E2	08/04/83	1345	1627.	100	2	54	610.	240.

Table 6. (Continued)

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* CODE *  *   DATE   *  *TIME*  *LAMP*  *LAMPS*  *    I    *  *    I    *  *    I    *  *    I    *
* DAY  *  *          *  *    *  *TEMP*  *  ON  *  *  METER* *  *  METER* *  *  METER* *  *  METER* *
*  NO  *  *          *  *    *  *(C) *  *      *  *    A    *  *    9    *  *    C    *  *    D    *

   266     08/23/82     0850     ****        72       *****        *****        *****        *****
   267     08/24/82     0800     ****        72       *****        *****        *****        *****
   268     08/25/82     0750     ****         0       *****        *****        *****        *****
   274     08/31/82              ****        70       *****        *****        *****        *****
   275     09/01/82     1530     ****        70       *****        *****        *****        *****
   281     09/07/82     0930     ****        52       *****        *****        *****        *****
   282     09/08/82     1130     ****        50       *****        *****        *****        *****
   296     09/22/82     1200     ****        38       *****        *****        *****        *****
   308     10/04/82     1200     ****         0       *****        *****        *****        *****
   309     10/05/82     1000     ****         0       *****        *****        *****        *****
   310     10/06/82     1015     ****         0       *****        *****        *****        *****
   315     10/12/82     1430     ****         0       *****        *****        *****        *****
   316     10/13/82     1100     ****         0       *****        *****        *****        *****
   321     10/18/82     1200     ****         0       *****        *****        *****        *****
   322     10/19/82     1000     ****         0       *****        *****        *****        *****
   329     10/25/82     1610     ****         0       *****        *****        *****        *****
   330     10/26/82     1215     ****         0       *****        *****        *****        *****
   331     10/27/82     1130     ****         0       *****        *****        *****        *****
   337     11/02/82     1000     ****         0       *****        *****        *****        *****
   338     11/03/82     1000     ****         0       *****        *****        *****        *****
   343     11/08/82     1300     ****         0       *****        *****        *****        *****
   345     11/10/82     1000     ****         0       *****        *****        *****        *****
   350     11/15/82     1130     ****         0       *****        *****        *****        *****
   351     11/16/82     1030     ****         0       *****        *****        *****        *****
   352     11/17/82     1130     ****         0       *****        *****        *****        *****
   353     11/18/82     1145     ****         0       *****        *****        *****        *****
   357     11/22/82     1430     ****        72       *****        *****        *****        137.1
   358     11/23/82     1100     ****        72        47.7         31.2         34.2         31.5
   364     11/29/82     1500     ****        72        59.2        111.6         99.0         73.7
   365     11/30/82     1300     ****        72        23.6         39.9         42.6         37.7
   366     12/01/82     1145     ****        72        37.4         33.5         56.8         45.6
   367     12/02/82     1200     ****        72        39.3         51.6         26.0         36.3
   371     12/06/82     1200     ****        70        33.6         23.1         13.0         17.6
   372     12/07/82     1130     ****        70        35.4          4.0          9.6         12.8
   373     12/08/82     1130     ****        70        32.9          2.4          6.5         18.4
   378     12/13/82     1200     ****        70        33.4         47.7         57.3         18.0
   379     12/14/82     1130     ****        64        34.2         22.8         34.5         14.3
   380     12/15/82     1430     ****        58        37.8          8.9         25.5         17.8
   381     12/16/82     1200     ****        66        33.5          1.4          5.9         11.2
   385     12/20/82     1130     ****        42       *****        *****        *****        *****
   386     12/21/82     1430     ****        66        63.3         11.7         21.3         44.4
   399     01/03/83     1230     ****         0       *****        *****        *****        *****
   400     01/04/83     1030     32.0        42        49.5         12.1         13.0         14.2
   401     01/05/83     1145     ****        62        61.6         13.3         19.3         20.8
   402     01/06/83     1030     ****        56        57.3         10.6         13.5         16.4
   406     01/10/83     1330     37.0        52        91.2          7.5         14.1        116.2
   407     01/11/83     1200     40.0        52        82.2          6.9         15.4         91.4
   408     01/12/83     1045     39.0        56        79.5          5.4         14.0         50.3
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Table 7. Unit 3 (Teflon System) Operating Conditions

```
* CODE *  *   DATE    *  *TIME*  *LAMP*  *LAMPS*  *   I   *  *   I   *  *   I   *  *   I   *
* DAY  *  *           *  *    *  *TEMP*  * ON   *  * METER*  * METER*  * METER*  * METER*
*  NO  *  *           *  *    *  *(C) *  *      *  *   A   *  *   B   *  *   C   *  *   D   *

   409       01/13/83     1145    ****      56       51.0        3.9        8.0       25.5
   413       01/17/83     1500    39.0      58       14.3        4.5       10.1       22.0
   414       01/18/83     1030    36.0      58       25.1        6.4       10.3       20.0
   415       01/19/83     1200    35.0      58       18.0        5.7       10.3       18.3
   416       01/20/83     1200    37.0      58       18.8        6.1        9.6       16.2
   420       01/24/83     1245    40.0      46       20.9        5.6        8.1       13.3
   421       01/25/83     1100    39.2      58       17.8        5.1        8.9       15.0
   422       01/26/83     1630    42.0      58       17.1        5.1        9.2       13.8
   423       01/27/83     1200    37.5      58       19.6        8.0       12.4       16.3
   427       01/31/83     1130    ****       0      *****      *****      *****      *****
   428       02/01/83             ****       0      *****      *****      *****      *****
   429       02/02/83             ****       0      *****      *****      *****      *****
   430       02/03/83             ****       0      *****      *****      *****      *****
   441       02/14/83     1230    ****       0      *****      *****      *****      *****
   444       02/17/83     1130    ****       0      *****      *****      *****      *****
   455       02/28/83     1100    ****       0      *****      *****      *****      *****
   462       03/07/83     1100    ****       0      *****      *****      *****      *****
   463       03/08/83     1100    ****       0      *****      *****      *****      *****
   464       03/09/83     1100    ****       0      *****      *****      *****      *****
   469       03/14/83     1145    ****      32      *****      *****      *****      *****
   470       03/15/83     0900    ****      24      *****      *****      *****      *****
   471       03/16/83     0900    ****      24      *****      *****      *****      *****
   472       03/17/83     1100    ****      24      *****      *****      *****      *****
   476       03/21/83     1130    ****      24      *****      *****      *****      *****
   477       03/22/83     1130    ****      24      *****      *****      *****      *****
   478       03/28/83     1415    ****      24      *****      *****      *****      *****
   479       03/24/83     1045    ****      24      *****      *****      *****      *****
   483       03/28/83     1030    ****      24      *****      *****      *****      *****
   484       03/28/83     0900    ****      24      *****      *****      *****      *****
   497       04/11/83     1300    ****       0      *****      *****      *****      *****
   498       04/12/83     1000    ****       0      *****      *****      *****      *****
   499       04/13/83     1115    ****       0      *****      *****      *****      *****
   500       04/14/83             ****      24      *****      *****      *****      *****
   504       04/18/83     1200    ****       0      *****      *****      *****      *****
   505       04/19/83     1030    ****       0      *****      *****      *****      *****
   506       04/20/83     1000    ****       0      *****      *****      *****      *****
   507       04/21/83     1145    ****      24      *****      *****      *****      *****
   511       04/25/83     1000    ****      24      *****      *****      *****      *****
   512       04/26/83     1000    ****      24      *****      *****      *****      *****
   513       04/27/83     0930    ****      24      *****      *****      *****      *****
   514       04/28/83     0900    ****       0      *****      *****      *****      *****
   520       05/04/83     1115    ****       0      *****      *****      *****      *****
   521       05/05/83     1130    ****       0      *****      *****      *****      *****
   574       06/27/83     0900    ****      22      *****      *****      *****      *****
   575       06/28/83     0900    ****      14      *****      *****      *****      *****
   576       06/29/83     0830    ****       0      *****      *****      *****      *****
   577       06/30/83     1100    ****       0      *****      *****      *****      *****
   589       07/12/83     1000    ****       0      *****      *****      *****      *****
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Table 7. (Continued)

```
* CODE *  *   DATE    *  *TIME*  *LAMP*  *LAMPS*  *   I   *  *   I   *  *   I   *  *   I   *
* DAY  *  *           *  *    *  *TEMP*  * ON   *  * METER*  * METER*  * METER*  * METER*
*  NO  *  *           *  *    *  *(C) *  *      *  *   A   *  *   B   *  *   C   *  *   D   *

   590      07/13/83     1030     ****        0      *****      *****      *****      *****
   591      07/13/83     1030     ****        0      *****      *****      *****      *****
   595      07/18/83     1000     ****        0      *****      *****      *****      *****
   596      07/19/83     1013     ****        0      *****      *****      *****      *****
   597      07/20/83     1045     ****        0      *****      *****      *****      *****
   602      07/25/83     1030     ****        0      *****      *****      *****      *****
   603      07/26/83     0915     ****        0      *****      *****      *****      *****
   604      07/27/83     0845     ****        0      *****      *****      *****      *****
   605      07/25/83     1030     ****       20      *****      *****      *****      *****
   609      08/01/83     0915     ****        0      *****      *****      *****      *****
   610      08/02/83     0905     ****        0      *****      *****      *****      *****
   611      08/03/83     0910     ****        0      *****      *****      *****      *****
   612      08/04/83     0915     ****        0      *****      *****      *****      *****
   616      08/08/83     0930     ****        0      *****      *****      *****      *****
   617      08/09/83     0930     ****        0      *****      *****      *****      *****
   618      08/10/83     0930     ****        0      *****      *****      *****      *****
   619      08/11/83     0910     ****        0      *****      *****      *****      *****
   630      08/22/83     0900     ****       22      *****      *****      *****      *****
   631      08/23/83     1000     ****       24      *****      *****      *****      *****
   632      08/24/83              ****       24      *****      *****      *****      *****
   633      08/25/83     1200     ****        0      *****      *****      *****      *****
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Table 7. (Continued)

CODE	DATE	TIME	FLOW L/MIN	BANKS ON	LAMPS ON	TOTAL COLI COL/100	FECAL COLI COL/100
266-200-E3	08/23/82	0940	1143.	36	72	31.	5.
266-201-E3	08/23/82	1135	2252.	36	72	13.	11.
266-202-E3	08/23/82	1345	2838.	36	72	19.	8.
267-203-E3	08/24/82	0930	1143.	36	72	12.	6.
267-204-E3	08/24/82	1145	2100.	36	72	12.	9.
267-205-E3	08/24/82	1410	2838.	36	72	15.	12.
274-209-E3	08/31/82		643.	35	70	80.	*******
275-210-E3	09/01/82	0900	2100.	35	70	170.	70.
275-211-E3	09/01/82	1100	643.	35	70	20.	2.
275-212-E3	09/01/82	1400	1438.	35	70	32.	18.
470-352-E3	03/15/83		189.	12	24	46.	34.
470-353-E3	03/15/83		378.	12	24	********	45.
471-354-E3	03/16/83	1130	378.	12	24	25.	21.
471-355-E3	03/16/83	1430	189.	12	24	32.	14.
472-356-E3	03/17/83	1130	927.	12	24	225.	135.
472-357-E3	03/17/83	1500	492.	12	24	89.	42.
483-364-E3	03/28/83	1130	529.	12	24	2700.	750.
483-365-E3	03/28/83	1500	529.	12	24	290.	220.
484-366-E3	03/29/83	1130	454.	12	24	560.	200.
484-367-E3	03/29/83	1500	378.	12	24	70.	40.
500-377-E3	04/14/83	0800	529.	12	24	19100.	8240.
500-378-E3	04/14/83	0925	378.	12	24	2850.	1230.
500-379-E3	04/14/83	1100	264.	12	24	590.	290.
500-380-E3	04/14/83	1415	529.	12	24	4100.	1600.
500-381-E3	04/14/83	1515	378.	12	24	570.	120.
500-382-E3	04/14/83	1600	264.	12	24	86.	55.
507-392-E3	04/21/83	0800	264.	12	24	159.	108.
507-393-E3	04/21/83	0930	378.	12	24	706.	268.
507-394-E3	04/21/83	1020	529.	12	24	1249.	350.
507-395-E3	04/21/83	0100	264.	12	24	117.	68.
507-396-E3	04/21/83	1315	378.	12	24	410.	158.
507-397-E3	04/21/83	1500	529.	12	24	1481.	425.
511-398-E3	04/25/83	1100	264.	12	24	127.	59.
511-399-E3	04/25/83	1200	378.	12	24	350.	186.
511-400-E3	04/25/83	1500	529.	12	24	9000.	5450.
512-401-E3	04/26/83	1230	264.	12	24	695.	601.
512-402-E3	04/26/83	1400	378.	12	24	3650.	1620.
512-403-E3	04/24/83	1530	529.	12	24	8050.	3150.
513-404-E3	04/27/83	1000	264.	12	24	1150.	640.
513-405-E3	04/27/83	1130	378.	12	24	5600.	3300.
513-406-E3	04/27/83	1530	529.	12	24	3450.	1440.
630-478-E3	08/22/83	1000	605.	11	22	6660.	4480.
630-479-E3	08/22/83	1200	359.	11	22	5110.	1800.
631-480-E3	08/23/83	1000	605.	12	24	15300.	6300.
631-481-E3	08/23/83	1200	473.	12	24	12500.	4330.
632-482-E3	08/24/83		605.	12	24	9490.	7000.
632-483-E3	08/24/83		473.	12	24	15700.	5800.

Table 8. Unit 3 (Teflon System) Effluent - Secondary

```
*   CODE    * *  DATE    * *TIME* *TURBIDITY* *  SS   * *  PH    * *  TOTAL      * *  FECAL      *
*           * *          * *    * *         * *       * *        * *COLIFORM     * * COLIFORM    *
*           * *          * *    * * ( NTU ) * *(MG/L)* *        * *(COL/100ML)* *(COL/100ML)*

   316-227     10/13/82     1400     *****      206.0       7.3      56555600.       30166700.
   329-234     10/25/82     1300      18.0       88.0       6.8      67700000.        7000000.
   329-235     10/25/82     1315       6.0       82.0       6.5     153500000.       19000000.
   329-236     10/25/82     1330      15.0       86.0       6.2      24300000.        8300000.
   381-286     12/16/82     1200      63.0      168.0       6.5      18000000.        9700000.
   381-287     12/16/82     1415      58.0      162.0       6.6      22000000.        3700000.
   463-346     03/08/83     1500      50.0      116.0       6.9      17000000.        3100000.
   476-358     03/21/83     1130      30.0      128.0       6.9       5900000.        1650000.
   476-359     03/21/83     1400      27.0      132.0       6.9       5300000.        3200000.
   638-488     08/30/83     1120      30.0       84.0       6.8      37500000.        2750000.
   638-489     08/30/83     1125      15.0       75.0       6.8      54300000.       22200000.
   638-490     08/30/83     1130      18.0       76.0       6.7      45500000.        1900000.
   638-491     08/30/83     1310      18.0       53.0       6.9      60300000.       28700000.
   638-492     08/30/83     1320      15.0       54.0       6.8      50000000.       34700000.
   638-493     08/30/83     1330      18.0       57.0       6.8      47000000.       27700000.
   639-494     08/31/83     1100      22.0       80.0       6.7      25500000.       22700000.
   639-495     08/31/83     1115      18.0       74.0       6.7      31000000.       17300000.
   639-496     08/31/83     1300      18.0       43.0       6.9      87300000.       12000000.
   639-497     08/31/83     1315      20.0       45.0       6.6      31300000.       24000000.
   640-498     09/01/83     1105      30.0       90.0       6.7      23750000.        7200000.
   640-499     09/01/83     1115      28.0      102.0       6.8      30500000.        8550000.
   640-500     09/01/83     1400      18.0       48.0       6.7      83500000.       28500000.
   640-501     09/01/83     1415      22.0       46.0       6.8     108000000.       44666696.
   645-502     09/06/83     1130      28.0       75.0       7.0      16666700.        8850000.
   645-503     09/06/83     1135      22.0       70.0       6.7      19666700.       10500000.
   645-504     09/06/83     1400      26.0       57.0       6.6      30500000.       11900000.
   645-505     09/06/83     1405      22.0       53.0       6.6      24666700.       12500000.
   646-506     09/07/83     1200      28.0       62.0       7.1      46500000.       11000000.
   646-507     09/07/83     1205      25.0       64.0       6.6      53000000.       11000000.
   646-508     09/07/83     1430      26.0       58.0       6.6      57500000.       22500000.
   646-509     09/07/83     1435      26.0       61.0       6.6      49500000.       19000000.
   647-510     09/08/83     1100      30.0       75.0       7.3      23250000.       11000000.
   647-511     09/08/83     1105      28.0       74.0       6.7      30333300.       16333300.
   647-512     09/08/83     1430      25.0       58.0       6.6      34666696.       13000000.
   647-513     09/08/83     1435      28.0       58.0       6.7      29000000.       14500000.
```

Table 9. Influent (Primary) to UV Units - Water Quality and Bacteriology

CODE	DATE	TIME	DIRECT UV TOTAL (CM-1)	DIRECT UV FILTER (CM-1)	SPHERE UV TOTAL (CM-1)	SPHERE UV FILTER (CM-1)
316-227	10/13/82	1400	0.437	0.366	0.368	0.327
329-234	10/25/82	1300	0.874	0.492	0.621	0.467
329-235	10/25/82	1315	1.060	0.527	0.754	0.495
329-236	10/25/82	1330	0.876	0.513	0.587	0.483
381-286	12/16/82	1200	1.288	0.883	1.104	0.752
381-287	12/16/82	1415	0.897	0.697	0.741	0.561
463-346	03/08/83	1500	1.113	0.989	0.607	0.589
476-358	03/21/83	1130	0.269	0.343	0.265	0.288
476-359	03/21/83	1400	0.327	0.446	0.331	0.396
638-488	08/30/83	1120	0.805	0.800	0.623	0.639
638-489	08/30/83	1125	0.722	0.846	0.547	0.658
638-490	08/30/83	1130	0.708	0.879	0.614	0.685
638-491	08/30/83	1310	0.745	0.996	0.665	0.764
638-492	08/30/83	1320	0.817	1.014	0.702	0.773
638-493	08/30/83	1330	0.787	1.035	0.573	0.764
639-494	08/31/83	1100	0.722	0.835	0.575	0.596
639-495	08/31/83	1115	0.879	0.881	0.704	0.635
639-496	08/31/83	1300	0.874	0.980	0.605	0.623
639-497	08/31/83	1315	0.844	0.984	0.584	0.610
640-498	09/01/83	1105	1.198	0.869	0.718	0.561
640-499	09/01/83	1115	1.139	0.872	0.639	0.575
640-500	09/01/83	1400	1.302	0.941	0.757	0.598
640-501	09/01/83	1415	1.157	0.902	0.669	0.598
645-502	09/06/83	1130	0.589	0.568	0.437	0.449
645-503	09/06/83	1135	0.664	0.619	0.518	0.430
645-504	09/06/83	1400	0.702	0.646	0.508	0.421
645-505	09/06/83	1405	0.718	0.649	0.524	0.423
646-506	09/07/83	1200	0.653	0.626	0.481	0.421
646-507	09/07/83	1205	0.989	0.623	0.534	0.409
646-508	09/07/83	1430	1.010	0.658	0.520	0.451
646-509	09/07/83	1435	1.058	0.679	0.619	0.462
647-510	09/08/83	1100	0.676	0.695	0.536	0.428
647-511	09/08/83	1105	1.080	0.741	0.559	0.451
647-512	09/08/83	1430	1.180	0.773	0.575	0.453
647-513	09/08/83	1435	1.200	0.789	0.593	0.444

Table 9A. Influent (Primary) to UV Units - UV Absorbance

```
*   CODE    * *  DATE   *  *TIME*  * COD  * * COD  * * TOC  * * TOC  * * TKN  * * TKN  * *NH3-N * *NO2-N * *NO3-N *
*           * *         *  *    *  *TOTAL * *FILTER* *TOTAL * *FILTER* *TOTAL * *FILTER* *      * *      * *      *
*           * *         *  *    *  *(MG/L)* *(MG/L)* *(MG/L)* *(MG/L)* *(MG/L)* *(MG/L)* *(MG/L)* *(MG/L)* *(MG/L)*

    316-227     10/13/82    1400    202.0     26.0     27.0     30.0   ******   ******   ******   ******   ******
    329-234     10/25/82    13'0    138.0     49.0     32.0     19.0     4.48     4.48    10.60    0.160    0.510
    329-235     10/25/82    1315    101.0     47.0     36.0     25.0     4.50   ******    10.20    0.380    0.710
    329-236     10/25/82    1330    147.0     42.0     19.0     20.0     5.80     5.90     9.87    0.090    0.450
    381-286     12/16/82    1200    169.0     42.0     38.6     33.5     7.10     8.40    12.00    0.220    0.380
    381-287     12/16/82    1415    140.0     29.0     39.4     24.5     7.90     6.20     5.50    0.110    0.500
    463-346     03/08/83    1500    146.0     43.0     17.0     19.0   ******   ******   ******   ******   ******
    476-358     03/21/83    1130     69.0     36.0     27.0   ******   ******   ******   ******   ******   ******
    476-359     03/21/83    1400    132.0     39.0     27.0   ******   ******   ******   ******   ******   ******
    638-488     08/30/83    1120    122.0     38.0     26.0     11.0   ******   ******   ******   ******   ******
    638-489     08/30/83    1125   ******   ******   ******   ******   ******   ******   ******   ******   ******
    638-490     08/30/83    1130   ******   ******   ******   ******   ******   ******   ******   ******   ******
    638-491     08/30/83    1310   ******   ******   ******   ******   ******   ******   ******   ******   ******
    638-492     08/30/83    1320   ******   ******   ******   ******   ******   ******   ******   ******   ******
    638-493     08/30/83    1330   ******   ******   ******   ******   ******   ******   ******   ******   ******
    639-494     08/31/83    1100    122.0     54.0     32.0     14.0   ******   ******   ******   ******   ******
    639-495     08/31/83    1115   ******   ******   ******   ******   ******   ******   ******   ******   ******
    639-496     08/31/83    1300   ******   ******   ******   ******   ******   ******   ******   ******   ******
    639-497     08/31/83    1315   ******   ******   ******   ******   ******   ******   ******   ******   ******
    640-498     09/01/83    1105    132.0     54.0     43.0     15.0   ******   ******   ******   ******   ******
    640-499     09/01/83    1115   ******   ******   ******   ******   ******   ******   ******   ******   ******
    640-500     09/01/83    1400   ******   ******   ******   ******   ******   ******   ******   ******   ******
    640-501     09/01/83    1415   ******   ******   ******   ******   ******   ******   ******   ******   ******
    645-502     09/06/83    1130    125.0    340.0     46.0     16.0   ******   ******   ******   ******   ******
    645-503     09/06/83    1135   ******   ******   ******   ******   ******   ******   ******   ******   ******
    645-504     09/06/83    1400   ******   ******   ******   ******   ******   ******   ******   ******   ******
    645-505     09/06/83    1405   ******   ******   ******   ******   ******   ******   ******   ******   ******
    646-506     09/07/83    1200    125.0     37.0     34.0     17.0   ******   ******   ******   ******   ******
    646-507     09/07/83    1205   ******   ******   ******   ******   ******   ******   ******   ******   ******
    646-508     09/07/83    1430   ******   ******   ******   ******   ******   ******   ******   ******   ******
    646-509     09/07/83    1435   ******   ******   ******   ******   ******   ******   ******   ******   ******
    647-510     09/08/83    1100    144.0     52.0     35.0     18.0   ******   ******   ******   ******   ******
    647-511     09/08/83    1105   ******   ******   ******   ******   ******   ******   ******   ******   ******
    647-512     09/08/83    1430   ******   ******   ******   ******   ******   ******   ******   ******   ******
    647-513     09/08/83    1435   ******   ******   ******   ******   ******   ******   ******   ******   ******
```

Table 9B. Influent (Primary) to UV Units - Water Quality

CODE	DATE	TIME	FLOW L/MIN	VOLTAGE (%)	BANKS ON	LAMPS ON	TOTAL COLI COL/100	FECAL COLI COL/100
316-227-E1	10/13/82	1400	1014.	100	3	98	540000.	240000.
329-234-E1	10/26/82	1305	1014.	100	3	92	47000.	4000.
329-236-E1	10/26/82	1330	2573.	100	3	92	110000.	50000.
381-286-E1	12/16/82	1200	1014.	100	3	94	3600000.	760000.
381-287-E1	12/16/82	1415	253.	100	3	94	625000.	190000.
476-358-E1	03/21/83	1130	321	100	3	94	22500.	1700.
476-359-E1	03/21/83	1400	473	100	3	94	2650.	325.
638-488-E1	08/30/83	1120	1835	100	2	58	30000000.	2300000.
638-489-E1	08/30/83	1125	813	100	2	58	340000.	200000.
638-490-E1	08/30/83	1130	1116	100	2	58	610000.	410000.
638-491-E1	08/30/83	1310	2365	100	2	58	3550000.	2900000.
638-492-E1	08/30/83	1320	1476	100	2	58	2650000.	940000.
638-493-E1	08/30/83	1330	1021	100	2	58	345000.	260000.
639-494-E1	08/31/83	1100	2365	100	2	58	2600000.	2100000.
639-495-E1	08/31/83	1115	813	100	2	58	260000.	155000.
639-496-E1	08/31/83	1300	1116	100	2	58	250000.	160000.
639-497-E1	08/31/83	1315	1835	100	2	58	3750000.	380000.
640-498-E1	09/01/83	1105	1078	100	2	58	520000.	190000.
640-499-E1	09/01/83	1115	813	100	2	58	465000.	220000.
640-500-E1	09/01/83	1400	662	100	2	58	235000.	21000.
640-501-E1	09/01/83	1415	378	100	2	58	345000.	20500.
645-502-E1	09/06/83	1130	2195	100	2	58	665000.	250000.
645-503-E1	09/06/83	1135	1362	100	2	58	215000.	110000.
645-504-E1	09/06/83	1400	529	100	2	58	5500.	1900.
645-505-E1	09/06/83	1405	302	100	2	58	3850.	1000.
646-506-E1	09/07/83	1200	2195	100	2	58	595000.	210000.
646-507-E1	09/07/83	1205	1362	100	2	58	250000.	110000.
646-508-E1	09/07/83	1430	529	100	2	58	24000.	3550.
646-509-E1	09/07/83	1435	302	100	2	58	2100.	900.
647-510-E1	09/08/83	1100	2195	100	2	58	39000.	19000.
647-511-E1	09/08/83	1105	1362	100	2	58	67500.	***********
647-512-E1	09/08/83	1430	529	100	2	58	34500.	4850.
647-513-E1	09/08/83	1435	302	100	2	58	490.	***********

Table 10. Unit 1 (Widely Spaced Quartz System) Effluent - Primary

```
*   CODE     * *   DATE   * *TIME* *  FLOW   * *VOLTAGE* *BANKS* *LAMPS* * TOTAL  * * FECAL  *
*            * *          * *    * *  L/MIN* *  (%)    * * ON    * *  ON   * *  COLI  * *  COLI  *
*            * *          * *    * *        * *         * *       * *       * *COL/100* *COL/100*

316-227-E2     10/13/82    1400     1014.       100         3         94        67500.      20000.
329-234-E2     10/26/82    1300     1014        100         3         88        37000.       3000.
329-236-E2     10/26/82    1330     2573        100         3         88       558900.     330000.
381-286-E2     12/16/82    1200     1014        100         3        100      1250000.     380000.
381-287-E2     12/16/82    1415      253        100         3        100        54500.      12000.
465-346-E2     03/08/83    1500      908        100         3        100        33500.       4350.
476-350-E2     03/21/83    1130      283        100         3         98         4400.        485.
476-359-E2     03/21/83    1400      473        100         3         98         5300.        500.
639-494-E2     08/31/83    1100     2365        100         2         48      3550000.    3000000.
639-495-E2     08/31/83    1115      913        100         2         48       520000.     290000.
639-496-E2     08/31/83    1300     1116        100         2         48    **********    210000.
639-497-E2     08/31/83    1315     1835        100         2         48      4450000.     300000.
640-498-E2     09/01/83    1105     1078        100         2         56       225000.      60000.
640-499-E2     09/01/83    1115      813        100         2         56       250000.      38000.
640-500-E2     09/01/83    1400      662        100         2         56        56000.      45000.
640-501-E2     09/01/83    1415      378        100         2         56       335000.      66000.
645-502-E2     09/06/83    1130     2195        100         2         44       465000.     200000.
645-503-E2     09/06/83    1135     1362        100         2         44       160000.     100000.
645-504-E2     09/06/83    1400      529        100         2         56         6600.       2750.
645-505-E2     09/06/83    1405      302        100         2         56         6300.       2550.
646-506-E2     09/07/83    1200     2195        100         2         56        95000.      16000.
646-507-E2     09/07/83    1205     1362        100         2         56       270000.      20000.
646-508-E2     09/07/83    1430      529        100         2         56         4950.       2200.
646-509-E2     09/07/83    1435      302        100         2         56         6150.       2500.
647-510-E2     09/08/83    1100     2195        100         2         56        66000.      43000.
647-511-E2     09/08/83    1105     1362        100         2         56        39500.      20000.
647-512-E2     09/08/83    1430      529        100         2         56         5300.       2000.
647-513-E2     09/08/83    1435      302        100         2         56         4800.       2600.
```

Table 11. Unit 2 (Closely Spaced Quartz System) Effluent - Primary

APPENDIX C

ANALYSIS OF MODEL DEVELOPMENT

Section 6, pages 58 to 65, describe the development of the proposed UV disinfection model. The analysis, in effect, presumes infinite boundaries on the upstream and downstream portions of the reactors. This is not a rigorous adherence to actual conditions which would describe the unit as a chemical reactor with finite boundary conditions. It can be demonstrated, however, that the approximation presented in Section 6 is an adequate representation of the more rigorous chemical reactor solution, as given by Levenspiel.* The following discussions present this analysis.

Recall Figure 6-1 from Section 6, and begin with the mass balance about the element of the UV reactor over a time interval Δt:

Change in Coliform Mass = Coliform In - Coliform Out - Coliform Loss

Assuming there are no sources or sinks of coliform other than decay (inactivation) within the element, the full equation is:

$$\underset{\text{(change)}}{V\Delta L} = \underset{\text{(input)}}{QL\Delta t} - \underset{\text{(output)}}{(Q + \Delta Q)\left(L + \frac{\partial L}{\partial x}\Delta x\right)\Delta t} - \underset{\text{(decay)}}{KVL\Delta t} \tag{C-1}$$

dividing by Δt and knowing that $V = A\Delta x$,

$$\frac{\Delta L}{\Delta t} = -\frac{Q}{A}\frac{\partial L}{\partial x} - \frac{L}{A}\frac{\Delta Q}{\Delta x} - \frac{\Delta Q}{A}\frac{\partial L}{\partial x} - KL \tag{C-2}$$

---

*Levenspiel, O., Chemical Reactor Engineering, 2nd Edition, John Wiley and Sons, New York, 1972.

If the infinitesimally small terms approach zero the equation becomes:

$$\frac{\partial L}{\partial t} = - \frac{1}{A} \frac{\partial (QL)}{\partial x} - KL \qquad \text{(C-3)}$$

This model, assuming no dispersion, is referred to as an advective model.

At steady state,

$$\frac{\partial L}{\partial t} = 0 \qquad \text{(C-4)}$$

and $L = L_o$ at $x = 0$

Q is constant in time, and A is a constant fixed by the dimensions of the reactor. Presuming the coliform to be non-conservative, Equation C-3 becomes:

$$0 = - \frac{Q}{A} \frac{dL}{dx} - KL \qquad \text{(C-5)}$$

or

$$u\frac{dL}{dx} + KL = 0 \qquad \text{(C-6)}$$

where u is the velocity. Integration yields:

$$L = L_o \exp \left[- \frac{Kx}{u}\right] \qquad \text{(C-7)}$$

Where x/u is equivalent to the time, t. The rate coefficient, K, will be a function of the UV intensity within the reactor.

Dispersion can be incorporated into Equation C-7 by again considering a mass balance about the elemental slice of the reactor. A dispersion term is included to account for the integrated effects of velocity and density gradients. The dispersion is assumed to occur in the direction of decreasing concentration gradients; thus, dispersion from the upstream face is negative and from the downstream face is positive.

The mass of coliform entering the upstream face due to dispersion over a time interval is:

$$(- EA \frac{\partial L}{\partial x}) \Delta t$$

where E is defined as the dispersion coefficient in units (L^2/T). The downstream output due to dispersion is written:

$$- (EA + \Delta EA) [\frac{\partial L}{\partial x} + \frac{\partial}{\partial x} (\frac{\partial L}{\partial x}) \Delta x] \Delta t$$

These expressions can be incorporated into Equation (C-1) (right side). Subsequent manipulation then yields:

$$\frac{\partial L}{\partial t} = - \frac{1}{A} \frac{\partial}{\partial x} (LQ) + \frac{1}{A} [\frac{\partial}{\partial x} (EA\frac{\partial L}{\partial x})] - KL \qquad \text{(C-8)}$$

At steady state, Equation (C-8) becomes:

$$0 = - \frac{1}{A} \frac{d}{dx} (LQ) + \frac{1}{A} [\frac{d}{dx} (EA \frac{dL}{dx})] - KL \qquad \text{(C-9)}$$

Let u = velocity = Q/A; assuming that $L = L_o$ at $x = 0$, and constant E and u, the expression becomes:

$$0 = E\frac{d^2L}{dx^2} - u\frac{dL}{dx} - KL \qquad \text{(C-10)}$$

where E and u are the purely dispersive and purely advective parameters, respectively.

The general solution of Equation (C-10) is given by:

$$L(x) = B\exp(jx) + D\exp(gx) \tag{C-11}$$

where j and g are given by,

$$j = \frac{u}{2E}\left[1 + \left(1 + \frac{4KE}{u^2}\right)^{1/2}\right] \tag{C-12}$$

$$g = \frac{u}{2E}\left[1 - \left(1 + \frac{4KE}{u^2}\right)^{1/2}\right] \tag{C-13}$$

The parameters B and D are arbitrary constants evaluated from boundary conditions. Whereas Equation (C-11) is general, the form of the boundary conditions reflect the physical arrangement of the system and as such they constrain the general solution to a specific system configuration. Generally, the more symmetric the physical configuration, the simpler the form of the boundary conditions, and subsequently, the final solution.

The analysis presented in Section 6 suggests that the solution to Equation (C-11) could be simplified, effectively describing an unbounded reactor where x extends from +∞ to −∞ and concentration $L = L_o$ at $x = 0$:

$$L(x) = L_o \exp(gx) \quad x \geq 0 \tag{C-14}$$

$$= L_o \exp(jx) \quad x \leq 0 \tag{C-15}$$

Only solutions at $x > 0$ are applicable in the consideration of the UV reactor. Substituting for g, the expression can be written:

$$L = L_o \exp^{\frac{ux}{2E}\left[1 - \left(1 + \frac{4KE}{u^2}\right)^{1/2}\right]} \tag{C-16}$$

Which is also given as Equation 6-11, in Section 6. By bounding the solution to a finite length, x = length of reactor, errors are introduced and the solution can only be considered an approximation. The limitations of the simpler approximation can be evaluated by first considering the rigorous solution for a UV reactor with "typical" boundary conditions.

The physical arrangement of the UV reactor suggests that before the vessel, the dispersion can be considered equal to zero. System designs typically involve piped inlets, or channel flow with uniform velocity across the plane of the reactor. It is also assumed that back-dispersion and back flow from the reactor to the influent section is not significant.

As soon as the fluid enters the reactor, the lamp/quartz sleeves of the reactor causes velocity gradients and dispersion, such that $E \neq$ zero = constant. The dispersion coefficient may be different after the reactor than that in the reactor.

Exposure to UV radiation is assumed to be the overwhelmingly dominant cause for the coliform decay in the system. It follows that,

$K = 0$ prior to reactor
$K \neq 0$ within the reactor
$K = 0$ after the reactor

Allow the reactor to extend from $x = 0$ to $x = X$; the influent chamber is fixed between $x = 1$ to $x = 0$. The system after the reactor ("effluent" section) is assumed to extend from $x = X$ to $x = X^*$, such that $X^* \gg X$. Additionally, the coliform concentration in the influent chamber is L_o.

The boundary conditions for this system are summarized as follows:

at $x = 0$

mass flux of coliform leaving influent chamber = mass flux of coliform entering UV reactor at $x = X$

mass flux of coliform leaving UV reactor = mass flux of coliform entering "effluent" section

at $x = X$
coliform concentration at end of UV reactor = coliform concentration at beginning of the effuent section

at $x > X^*$
the coliform concentration would be bounded.

When these boundary conditions are applied to the general solution, the expression becomes:

$$L(x) = L_o \frac{g \exp(gX + jx) - j \exp(jX + gx)}{g(1 - j\frac{E}{u}) \exp(gX) - j(1 - g\frac{E}{u}) \exp(jX)} \qquad \text{(C-17)}$$

where x is any point within the UV reactor. To determine the effluent concentration, i.e., L at $x = X$, substitute Equations C-12 and C-13; by algebraic manipulation, the expression becomes:

$$L(x) = L_o \frac{4a \exp(\frac{uX}{2E})}{(1 + a)^2 \exp(\frac{auX}{2E}) - (1 - a)^2 \exp(\frac{auX}{2E})} \qquad \text{(C-18)}$$

where:

$$a = (1 + \frac{4KE}{u^2})^{1/2}$$

Levenspiel states that the first order reaction solution represented by Equation (C-18) is appropriate for vessels with any kind of entrance and exit conditions.

The modified expression suggested in Section 6, is generally valid in most applications to UV system design. The two solutions (Equations C-16 and C-18) can be shown to converge at the two extreme conditions of plug flow ($E \to 0$) and complete mix ($E \to \infty$). There will be a divergence of the two solutions if the reactor behavior deviates significantly from these two conditions. All UV system designs entail the use of a dispersive plug flow reactor; the first solution (Equation C-16) will be sufficient within an acceptable deviation from an ideal plug flow reactor.

In order to demonstrate the relationship between the two expressions, consider the ratio of the generalized solutions:

R = Ratio (Equation C-16/Equation C-18)

$$R = \frac{\exp(gx)}{\dfrac{g \exp(gX + jx) - j \exp(jX + gx)}{g(1 - j\frac{E}{u}) \exp(gX) - j(1 - g\frac{E}{u}) \exp(jX)}} \qquad \text{(C-19)}$$

at $x = X$

$$R = \frac{\exp(gX)}{\dfrac{g \exp(gX + jX) - j \exp(jX + gX)}{g(1 - j\frac{E}{u}) \exp(gX) - j(1 - g\frac{E}{u}) \exp(jX)}} \qquad \text{(C-20)}$$

where:

$$g = \frac{u}{2E}(1 - a) \qquad \text{(C-21)}$$

$$j = \frac{u}{2E}(1 + a) \qquad \text{(C-22)}$$

and $$a = \left(1 + \frac{4KE}{u^2}\right)^{1/2} \qquad \text{(C-23)}$$

Algebraic manipulation will then reduce the expression to:

$$R = \frac{(1 + a)^2 - (1 - a)^2 e^{-\frac{uXa}{E}}}{4a} \qquad \text{(C-24)}$$

Consider the dimensionless parameters,

$$P = \frac{uX}{E} \qquad \text{(C-25)}$$

and

$$r = \frac{KX}{u} \qquad \text{(C-26)}$$

the ratio,

$$\frac{r}{P} = \frac{KE}{u^2} \qquad \text{(C-27)}$$

and

$$a = \quad 1 + \frac{4EK}{u^2} = \quad 1 + \frac{4r}{P} \qquad \text{(C-28)}$$

As P approaches infinity, plug flow conditions exist. (Conversely, as P becomes small the system approaches complete mix). Under conditions of P being very large, causing 4r/P to be small, it is appropriate to approximate the value a by expansion:

$$a = \sqrt{1 + \frac{1}{2}(\frac{4r}{P})} = \sqrt{1 + \frac{2r}{P}} \qquad \text{(C-29)}$$

Substitute into Equation C-24:

$$R = \frac{4(1 + \frac{r}{P})^2 - 4(r/P)^2 e^{-P(1 + \frac{2r}{P})}}{4(1 + \frac{2r}{P})} \qquad \text{(C-30)}$$

the $(1 + r/P)^2$ term, at a very high P, can also be approximated by expansion to:

$$(1 + \frac{r}{P})^2 \approx 1 + \frac{2r}{P} \qquad \text{(C-31)}$$

Substitution and further manipulation yields:

$$R = \frac{(1 + \frac{2r}{P}) - (\frac{r}{P})^2 e^{-P} e^{-2r}}{1 + \frac{2r}{P}} = 1 \text{ (at very high P)} \qquad \text{(C-32)}$$

From this expression, at large values of P, (P → ∞) the ratio R is approximately unity. Note that the individual solutions, when evaluated at high values of P, yield a purely advective condition. This is demonstrated by considering the modified expression (Equation C-16):

$$\frac{L}{L_o} = e^{\frac{uX}{E}(1 - (1 + \frac{4KE}{u^2})^{1/2})} \qquad \text{(C-33)}$$

or

$$\frac{L}{L_o} = e^{P(1 - (1 + \frac{4r}{P})^{1/2})} \qquad \text{(C-34)}$$

at very large P,

$$\frac{L}{L_o} = e^{P[1 - (1 + \frac{2r}{P})]} = e^{P(\frac{-2r}{P})} = e^{-2r} \qquad \text{(C-35)}$$

Returning to Equation (C-30), it is apparent that the reduced expression relies on the accuracy in expanding the term for a. In general form, setting $4r/P = x$, the expansion is:

$$(1 + x)^n = 1 + nx - \frac{n(n-1)x^2}{2!} + \ldots \text{ for } x^2 < 1 \qquad \text{(C-36)}$$

Thus,

$$(\frac{4r}{P})^2 < 1 \qquad \text{(C-37)}$$

or

$$(\frac{r}{P})^2 < 0.25 \quad \text{and} \quad 2r^2 < P^2 \qquad \text{(C-38)}$$

Having cut the expansion at the second order term, this second order term:

$$\frac{-\frac{1}{2}(\frac{1}{2} - 1)x^2}{2!} = \frac{x^2}{8} = \frac{2r^2}{P^2} \qquad \text{(C-39)}$$

becomes an estimate of the error associated with the approximation of a.

The above analysis suggests that the modified expression presented by Equation (C-16) is a sufficient approximation of Equation (C-18) under conditions in which:

$$(\frac{r}{P})^2 \ll 0.25$$

or

$$(\frac{KE}{u^2})^2 \ll 0.25 \qquad \text{(C-40)}$$

In most cases with existing systems, this condition is met. In the case of the design protocol suggested by Section 8 (which utilizes Equation C-16) the condition of Equation C-40 must always be met.

Effect of Particulates

Recall from page 64, Equation (6-12), that the effect of particulates can be considered additive. Again, a rigorous formulation should also show this as an element of the initial density:

$$L = (L_o' + L_{particulate}) \exp (F) + L_{particulate} \qquad (C-41)$$

where:

$$F = \{\frac{ux}{2E} [1 - (1 + \frac{4KE}{u^2})^{1/2}]\}$$

and

L_o' = initial, non-aggregated density.

However, it can be assumed that

$$L_o' \gg L_p$$

such that the total initial density, L_o', can be considered equal to $[L_o' + L_{particulate}]$. In this case, it is reasonable to write the expression:

$$L = L_o \exp (F) + L_{particulate} \qquad (C-42)$$

Equation (C-42) is equivalent to Equation (6-12).